



**GEO-CENTERS**

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for Naval Weapons*

*Final Report  
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## 1.0 INTRODUCTION

This report is a summary of GEO-CENTERS, INC. research efforts for the Naval Research Laboratory (NRL) under Contract Number N00014-96-C-2097, entitled "Development of Materials for Naval Weapons." The period of performance was from August 15, 1996 through November 27, 2000. The work was carried out at NRL using NRL Materials Science and Technology (MS&T) Division and other NRL facilities, and at other locations and contractor facilities, in collaboration with government scientists and other contractors. The various research projects under this contract are generally divisible into the three main groups provided in the contract Statement of Work: development of advanced materials; testing and evaluation of advanced materials; and applications engineering and system development. In addition, support was provided to Navy environmental programs. Specific areas addressed during the current period of performance include:

- Basic and applied research, conducted on-site at NRL, to characterize the structural properties of materials through physical measurements, modeling and computational mechanics.
- Research and engineering on the corrosive effects of seawater on materials and the development of methods including Impressed Current Cathodic Protection to mitigate these effects. This work was performed primarily on-site at NRL's Marine Corrosion Laboratory in Key West, FL.
- Test and evaluation of materials conducted at GEO-CENTERS Materials Testing Laboratory housed near NRL in Clinton, MD.
- Chemical and Biological (C/B) detection through the integration of Surface Acoustic Wave (SAW) and Ion Mobility Spectroscopy (IMS) sensor technologies. Application of these sensor technologies into counterproliferation programs as sponsored by the Defense Threat Reduction Agency (DTRA).
- Application of materials science to the development, prototyping and deployment of systems for the treatment and disposal of the multiple waste streams from Navy ships.
- Study of environmental regulatory policies and procedures and support of the Shipboard Environmental Information Clearinghouse and Environmentally Sound Ships for the 21<sup>st</sup> Century programs.

Detailed descriptions of the tasks accomplished are provided in the following paragraphs. Where the work has been previously reported or published, brief summaries are provided or examples given followed by a listing of the publications where the detail can be found. Unpublished and unreported work is presented here in more detail. A listing of monthly progress reports provided as deliverables under this contract and a glossary of acronyms used in this report are appended.

## 2.0 DEVELOPMENT OF ADVANCED MATERIALS

Under previous contracts, GEO-CENTERS has supported the Materials Science and Technology Division in the development, test, and evaluation of a broad range of advanced materials, such as structural alloys, ceramics, composites, superconducting materials, and coatings. In the effort described herein, we have continued to provide diverse expertise to address a broad range of materials problems with emphasis on the areas of chemical sensors, marine corrosion, superconductors, thin films, environmental effects, materials testing, and computer modeling of materials and structures.

### 2.1 MICROSENSORS

GEO-CENTERS supported NRL in the research and development of miniature chemical detectors. This work involved applying commercial off the shelf (COTS) components to fabricate state-of-the art detector systems utilizing chemoselective polymers developed by NRL. Based on the requirements of the DOD sponsors, custom chemical detectors were fabricated to specifications.

We also supported the characterization of the chemoselective polymers developed at NRL and were responsible for the experimental setups, and the design of the characterization protocols. All of the characterization and testing equipment was maintained and calibrated by GEO-CENTERS.

Our work in support of this effort is reported in detail in the following publications and proceedings:

A. Pique, D.B. Chrisey, J.M. Fitzgerald, R. Chung, et al, "Direct Writing of Electronic and Sensor Materials Using a Laser Transfer Technique," *J. Mater. Res.* 15: (9), 1872-1875, September 2000.

R.A. McGill, T.E. Mlsna, R. Chung, et al, "The Design of Functionalized Silicone Polymers for Chemical Sensor Detection of Nitroaromatic Compounds," *Sensor Actuat B-Chem.* 65: (1-3), 5-9, June 30, 2000.

R.A. McGill, V.K. Nguyen, R. Chung, et al, "The "NRL-SAWRHINO": A Nose for Toxic Gases," *Sensor Actuat B-Chem.* 65: (1-3), 10-13, June 30, 2000.

A. Pique, R.A. McGill, D.B. Chrisey, R. Chung, et al, "Growth of Organic Thin Films by the Matrix Assisted Pulsed Laser Evaporation (MAPLE) Technique," *Thin Solid Films* 356, 536-541, November 1999.

D.D. Dominguez, R. Chung, V. Nguyen, et al, "Evaluation of SAW Chemical Sensors for Air Filter Lifetime and Performance Monitoring," *Sensor Actuat B-Chem* 53: (3), 186-190, December 10, 1998.

R.A. McGill, R. Chung, D.B. Chrisey, P.C. Dorsey, P. Matthews, A. Pique, T.E. Mlsna, and J.L. Stepnowski, "Performance Optimization of Surface Acoustic Wave Chemical Sensors," IEEE Transactions on Ultrasonics, Ferroelectrics and Frequency Control, Volume 45 Issue 5, 1370-1380 (1998).

D. DiLella, R.E. Shaffer, R.A. McGill, and R. Chung, "Algorithms for the Real-Time Analysis of SAW Chemical Sensor Array Data," Proceedings of the 1998 IEEE International Frequency Control Symposium, pp. 639-644 (1998).

D.D. Dominguez, R.A. McGill, R. Chung, and V. Nguyen, "Performance of an Embedded SAW Sensor for Filter Bed Monitor and the Development of a Wireless Monitoring Prototype System," Proceedings of the 1998 IEEE International Frequency Control Symposium, pp. 602-607 (1998).

R. Chung and R.A. McGill, "Performance of a Polymer Coated SAW Device Under Pulse Excitation," Proceedings of the IEEE International Frequency Control Symposium, pp. 634-638 (1998).

R. Chung, R.A. McGill, and P. Matthews, "Phase Noise Characterization of Polymer Coated-SAW Gas Sensors: Implications for the Performance of an Oscillator Circuit," IEEE Proceedings of the International Frequency Control Symposium, pp. 169-174 (1997).

R.A. McGill, D.B. Chrisey, T.E. Mlsna, J.L. Stepnowski, R. Chung, and H. Cotal, "Performance Optimization of Surface Acoustic Wave Chemical Sensors," Proceedings of the IEEE International Frequency Control Symposium, pp. 140-146 (1997).

R.E. Shaffer, M.T. Cygan, S.J. Hart, R. Chung, V. Nguyen, D. Dilella, and R.A. McGill, "Internal Standardization and Calibration of Surface Acoustic Wave Chemical Sensor Systems," Proceedings of the SPIE, volume 3537, pp.213-223 (1999).

P. Kobrin, C. Seabury, C. Linnen, A. Harker, R. Chung, R.A. McGill, and P.J. Matthews, "Thin Film Resonators for TNT Vapor Detection," Proceedings of the SPIE, volume 3392, pt.1-2, pp.418-423 (1998).

R.A. McGill, T.E. Mlsna, R. Chung, V.K. Nguyen, J. Stepnowski, M.H. Abraham, and P. Kobrin, P., "Sorbent Coatings for Nitroaromatic Vapors: Applications with Chemical Sensors," Proceedings of the SPIE, volume 3392, pt.1-2, pp.384-389 (1998).

D.B. Chrisey, A. Pique, R.C.Y. Auyeung, R.A. McGill, R. Chung, S. Lakeou, P. Wu, J. Fitzgerald, H.D. Wu, and M. Duignan, "A New Approach to Laser Direct Writing Active and Passive Mesoscopic Circuit Elements," Proceedings, Symposium on Surface Engineering: Science and Technology I., Minerals, Metals & Materials Society, pp.143-154 (1999).

E.J. Houser, R.A. McGill, T.E. Mlsna, V.K. Nguyen, R. Chung, and R.L. Mowery, "Sorbent Coatings for Detection of Explosives Vapor: Applications with Chemical Sensors," Proceedings of the SPIE, volume 3710, pt.1-2, pp.394-401 (1999).

C. Linnen, P.H. Kobrin, C. Seabury, A.B. Harker, R.A. McGill, E.J. Houser, R. Chung, R. Weber, and T. Swager, "Thin Film Resonators as Mass Transducers for Explosives Detection in Mine Fields," Proceedings of the SPIE, volume 3710, pt.1-2, pp.328-334 (1999).

A. Pique, D.B. Chrisey, R.C.Y. Auyeung, S. Lakeou, R. Chung, R.A. McGill, P.K. Wu, M. Duignan, J. Fitzgerald, and H.D. Wu, "Laser Direct Writing of Circuit Elements and Sensors," Proceedings of the SPIE, volume 3618, p.330-339 (1999).

## 2.2 MATERIALS MODELING

### 2.2.1 Computational Mechanics

As modern computers continue to advance in terms of speed and storage, the role of computational mechanics as it relates to the modeling of heterogeneous material behavior, smart materials, acoustical response, optimization of material and structural performance, and fluid-structure interaction becomes increasingly important. However, in addition to the increase in raw computing power, further improvements in numerical methods and mechanics are still required to meet future performance and cost goals.

An important area of great concern for the development of accurate and efficient computational models of materials and structures is the problem of the coupling of scales - from the micro- to meso- and macro- (or structural) scales. The influence of the micro- and meso-scales on the macro or structural response is still not well understood nor accounted for. Even with current computer capabilities, which include parallel processing, the direct inclusion of multiple scales is extremely limited since such models can easily require hundreds of thousands or millions of unknowns in the analyses. At NRL a significant effort is underway to better couple multiscales. The direct coupling of material scans to computer models and the development of Frequency Windowing Reduction (FWR) methods are two such related areas.

Under this contract, GEO-CENTERS has collaborated with NRL in making significant contributions in the following areas:

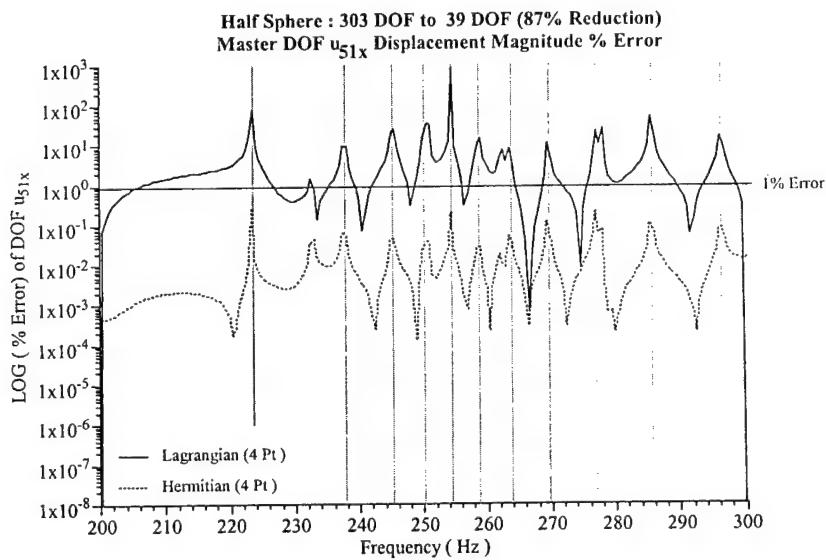
- modeling porous and heterogeneous media
- a new acoustic frequency windowing reduction method
- optimization studies of smart materials
- finite element models based directly upon images and scans

- a new two dimensional (2D) multiphase finite element for easier modeling of heterogeneous media
- fluid-structure interaction via the ABAQUS/RP computer program
- new and important basic improvements to Smooth Particle Hydrodynamics (SPH) methods which are used in dynamic fracture and fragmentation problems of interest to DOE and DOD.

The 2D multiphase finite element has been implemented into the ABAQUS commercially available finite element program. This element builds stiffness matrices directly from material scans using uniform meshes. In addition, this approach assumes that scan information is not usually available for an entire structure or structural component. Thus, the multiphase element can be applied to realistic structures, as well as smaller meso-scale models.

In the area of SPH methods, GEO-CENTERS has solved a fundamental problem in the field, which was instability in tension, via an approach called the stress point method. The stress point method also increased the accuracy of the SPH method, and is regarded as a major development in these particle methods.

The ABAQUS finite element code was used extensively in several of these areas of research and development. Future efforts will focus more on parallel processing to allow the solution of the much larger models that will be required for 3D analyses.



**Figure 1. Results from the FWR program for a reduced model of a half sphere shell structure within a selected frequency range.**

Figure 1 indicates results from the FWR program for the frequency response of a spherical shell model in which the degrees of freedom (DOF) in the original model have been reduced 87% within the frequency window of 200 - 300 Hertz. As indicated, the results show error of under 1% across this frequency window, which includes several resonances. Further improvements to accuracy are planned as well. In the future, this effort will begin work in the area of electromagnetics. The NRL-developed Frequency Window Reduction (FWR) computer program is expected to have significant impact. The reduction scheme used is based upon projection operators and deals with the entire governing differential equations rather than individual matrices. Interpolation methods are then introduced in the frequency domain to yield highly accurate solutions from the reduced model across wide frequency windows.

GEO-CENTERS work supporting NRL in investigating these and other topics in computational mechanics has been described in detail in the following publications, reports, and presentations:

C. Dyka, P.W. Randles, and R.P. Ingel, "Stress Points for Tension Instability in SPH," International Journal for Numerical Methods Engineering, volume 40, pp. 2325-2341 (1997).

C. Dyka, R.P. Ingel, and G.C. Kirby, "Stabilizing the Retarded Potential Method for Transient Fluid-Structure Interaction Problems," International Journal for Numerical Methods in Engineering, volume 40, pp. 3767-3783 (1997).

C. Dyka and R. Badaliance, "Damage in Marine Composites Due to Shock Loadings," Composites Science and Technology, 58, pp. 1433-1442 (1998).

C. Dyka and R.P. Ingel, "Transient Fluid-Structure Interaction in Naval Applications Using the Retarded Potential Method," Engineering Analysis with Boundary Elements (in press).

C. Dyka, R.P. Ingel, and H.Y. Yu, "Implementation and Further Development of New Shape Memory Alloy Constitutive Models into ABAQUS," presented to ABAQUS Users' Conference, Newport, RI, May 1998.

"Shock and Damage in Marine Composite Structures," NRL Memorandum Report MR/6384-96-7907, December 1996.

"Optimization of the Acoustic Performance of a Simple Thick Plate with Embedded Actuators," NRL Memorandum Report, December 1998.

A. Kee, P. Matic, and L. Popels, "A Two-Dimensional Computational Study of a Gasar Porous Copper Microstructure," Materials Science and Engr., Volume A225, pp. 85-95 (1997).

A. Kee, P. Matic, and J.M. Wolla, "A Computational Study of Elongated Pore Interactions in a Low Density Porous Copper," Materials Science and Engr., Volume A230, pp. 14-24 (1997).

R.J. Bonenberger, A.J. Kee, R.K. Everett, and P. Matic, "Characterization of Porous GASAR Aluminum," Porous and Cellular Materials for Structural Applications, MRS Symposium Proceedings, Volume 521, D. S. Schwartz, D. S. Shih, A. G. Evans, and H. N. G. Wadley, eds., MRS, Warrendale, PA, pp. 303-314 (1998).

R.K. Everett, P. Matic, D.P. Harvey II, and A. Kee, "The Microstructure and Mechanical Response of Porous Polymers," Materials Science and Engr., volume A249, pp. 7-13 (1998).

A. Kee, P. Matic, and R.K. Everett, "A Mesoscale Simulation of Multiaxial Yield in GASAR Porous Copper," Materials Science and Engr., volume A249, pp. 30-39 (1998).

R.K. Everett, P. Matic, D. Harvey II, and A. Kee, "Microstructure and Properties of Porous Polymers," McNU'97-ASME/ASCE/SES Summer Meeting, Evanston, IL, June 1997.

A. Kee, P. Matic, and T. Jessen, "A Mesoscale Analysis on the Effects of Pore Morphology in Porous Materials and Matrix Morphology in Fiber Reinforced Composites," 1997 ABAQUS Users Conf. Proc., Milan, Italy, pp. 421-435, June 1997.

A. Kee, J. Morris, and P. Matic, "A Mesoscale Computer Simulation of Multiaxial Yield Phenomena in Gasar Porous Copper," McNU'97-ASME/ASCE/SES Summer Meeting, Evanston, IL, June 1997.

A. Kee, J. Morris, and P. Matic, "Microstructural and Mesoscale Computer Simulations of Multiaxial Yield, Flow and Fracture Phenomena in Porous Metals," Fourth U.S. National Congress on Computational Mechanics, San Francisco, CA, August 1997.

P. Matic, A.B. Geltmacher, and A. Kee, "Cellular Simulations of Damage Evolution and Fracture," McNU'97-ASME/ASCE/SES Summer Meeting, Evanston, IL, June 1997.

R.J. Bonenberger, A.J. Kee, R.K. Everett, and P. Matic, "Characterization of Porous GASAR Aluminum," MRS 1998 Spring Meeting, San Francisco, CA, April 1998. (Invited presentation)

P. Matic and A. Kee, "Microplastic Connectivity and Macroplasticity," 127th TMS Annual Meeting, San Antonio, TX, February 1998.

P. Matic and A. Kee, "Connectivity Based Analysis of Yield and Damage," 1998 Ductile Fracture Workshop, Pennsylvania State University, University Park, PA, September 1998.

P. Matic, A. Kee, and A. Geltmacher, "Evolution of Plastic Flow Across Complex Microstructures," 13th U.S. National Congress of Applied Mechanics, Gainesville, FL, June 1998.

C. Dyka, "Shock and Damage in Marine Composite Structures", NRL Memorandum Report NRL/MR/6384-96-7907, December 31, 1996.

C. Dyka and G.C. Kirby, "Optimization of the Acoustic Performance of a Simple Plate with Embedded Actuators," NRL Memorandum Report 6350-98-8329, December 31, 1998.

C. Dyka, R.P. Ingel and L.D. Flippen, "Interpolation-Based Condensation Model Reduction for Applications to Structural Acoustics," NRL Memorandum Report, NRL/MR/6350-99-8402, September 30, 1999.

## 2.2.2 Porous Shape Memory Alloys

Shape memory alloys (SMAs) have emerged as a class of materials with unique thermal and mechanical properties that have found numerous applications in various engineering areas. While the shape memory and pseudoelasticity effects have been extensively studied, only a few studies have been done on the high capacity of energy dissipation of SMAs. Because of this property, SMAs hold the promise of making high-efficiency damping devices that are superior to those made of conventional materials. In addition to the energy absorption capability of the dense SMA material, porous SMAs offer the possibility of higher specific damping capacity under dynamic loading conditions, due to scattering of waves. Porous SMAs also offer the possibility of impedance matching by grading the porosity at connecting joints with other structural materials. As a first step, the focus of GEO-CENTERS' collaboration with NRL in studying these materials is on establishing the static properties of porous SMA material. To accomplish this, a micromechanics-based analysis of the overall behavior of porous SMA is carried out. The porous SMA is modeled as a composite with SMA matrix, which is modeled using an incremental formulation, and pores as inhomogeneities of zero stiffness. The macroscopic constitutive behavior of the effective medium is established using the incremental Mori-Tanaka averaging method for a random distribution of pores, and a FEM analysis of a unit cell for a periodic arrangement of pores. Results from both analyses are compared under various loading conditions.

Further work focuses on establishing the properties -- both static and dynamic -- of porous SMA materials, and their energy absorption capabilities. To accomplish this, micromechanics-based analysis of the overall behavior of SMAs was carried out. The porous SMA was modeled as a composite with a solid SMA matrix, which was in turn described by a constitutive model available in the literature, and elastic inclusions, which in the limit represent the voids in the porous material. The static macroscopic constitutive behavior of the material was established using both the Mori-Tanaka averaging method and the unit cell finite element method. The dynamic macroscopic constitutive behavior was described using the results obtained by the Mori-Tanaka averaging method.

Shape memory alloys are frequently used in smart materials and structures as the active component. Their ability to provide high force and large displacements has been used to the advantage in many applications. The majority of applications to date utilize solid shape memory alloy materials in quasi-static loading conditions. Recent work has proposed the use of porous SMAs as an energy absorbing material under dynamic loading conditions. The use of porous SMAs under dynamic loading will require advancements in the understanding of SMA behavior



both in the dense or solid form and in the porous form. The current work examines the quasi-static behavior of porous SMA as a first step. The material behavior is modeled on a mesoscale level allowing for the examination of pore size and shape variation effects. Bulk material response is estimated and compared with micromechanical periodic unit cell predictions.

We have used micromechanical averaging methods to estimate the porous shape memory alloy material behavior. The material is assumed to consist of two components: the dense shape memory alloy matrix and the pores (or voids). An existing rate-independent type constitutive model is employed to describe the matrix behavior. Two contrasting strategies were used to estimate overall behavior: the unit cell finite element method (UCFEM) to account for periodic distribution of pores in the matrix; and the Mori-Tanaka method (MTM) to account for random distribution of pores in the matrix. Cylindrical and spherical shapes are considered as approximations of open and close pores, respectively, in both methods. Results are presented for both types of pores and comparisons are made between the two methods under various loading conditions. Both methods compare well in predicting the elastic material properties and transformation under tensile and out-of-plane shear loading. However, the transformation results differ under transverse and in-plane shear loading. This difference is found to be due to the use of averaged value of stress at a material point in the MTM, which homogenizes the effect of local stress concentration thereby delaying the onset of phase transformation due to applied load. On the other hand, the actual value of stress at a material point is used in the UCFEM causing phase transformation in regions near the pores earlier than what is calculated by the MTM.

Detailed reports of our porous shape memory alloys research, summarized above, have been submitted to the NRL project manager and published or submitted for publication as follows:

V.G. DeGiorgi and M.A. Qidwai, "Mesoscale Analysis of Porous Shape Memory Alloys," Adaptive Structures and Material Systems, Eds., J. Redmond and J. Main, AD-Vol. 60, pp. 33-39 (2000).

D.C. Lagoudas, P.B. Entchev, M.A. Qidwai, and V.G. DeGiorgi, "Micromechanics of Porous Shape Memory Alloys," Adaptive Structures and Material Systems, Eds., J. Redmond and J. Main, AD-Vol. 60, pp. 40-50 (2000).

D.C. Lagoudas, P.B. Entchev, E.L. Vandygriff, M.A. Qidwai, and V.G. DeGiorgi, "Modeling of Porous Shape Memory Alloy Behavior," Smart Structures and Materials 2000: Active Materials: Behavior and Mechanics, Ed. C.S. Lynch, SPIE Vol. 3992, pp. 496-508, (2000).

M.A. Qidwai, P.B. Entchev, D.C. Lagoudas, and V.G. DeGiorgi, "Estimate of Porous Shape Memory Alloy Material Behavior," International Journal of Solids and Structures (submitted).

## 2.3 SUPERCONDUCTING MAGNET SYSTEMS AND THIN FILMS

During the period of performance, GEO-CENTERS has supported NRL Code 6340 in the maintenance of superconducting magnet systems and the preparation and characterization of thin superconducting films and other thin films. We have supported the operation and maintenance of the Rotatable High Field Facility's 6 tesla superconducting magnet and the American Superconductor 7.2 tesla and Cryomagnetics 14 tesla superconducting magnets of the High Field Magnets Facility. We have been responsible for maintaining liquid nitrogen and liquid helium coolant systems; ordering and transferring the cryogenic materials and other gasses; maintaining liquid levels in the magnet cryostats; conducting procedures to cool the magnets; and ramping up the magnets to the desired field. We also provided support for installing, plumbing, and repairing the cryogenic transfer systems and other peripheral equipment.

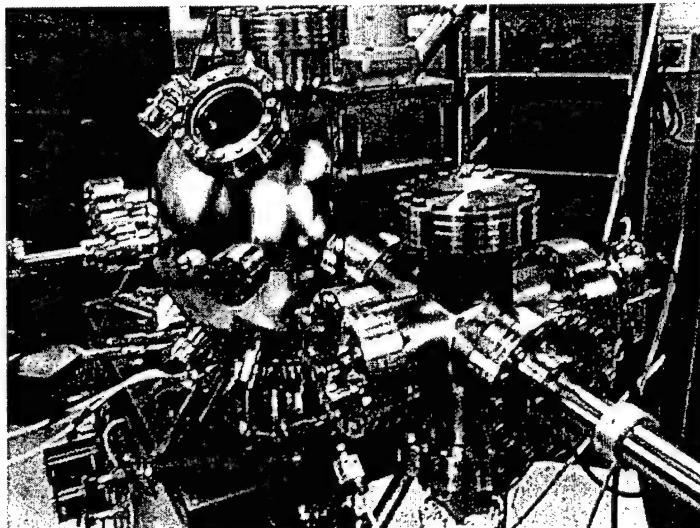
A typical procedure in support of the Rotatable High Field Facility is to cool the magnet in preparation for its operation. The magnet's temperature is maintained by a cryostat containing three concentric chambers: an outer vacuum case (OVC) to isolate the inner chambers from the room temperature, an intermediate liquid nitrogen container, and an inner liquid helium container. If the OVC has been open to the atmosphere, it must be purged with dry nitrogen gas and evacuated using a vacuum pump. The liquid nitrogen container is then filled and the level maintained by at least daily inspection or by a liquid nitrogen level controller. Before filling the liquid helium chamber, the magnet must be cooled below 100 K. First the cryostat is filled with liquid nitrogen and allowed to pre-cool overnight. The cryostat is then evacuated and filled with helium gas. After repeating this cycle a few times to ensure that the magnet is thoroughly purged of nitrogen, the cryostat can be filled with liquid helium. When magnet resistance drops to zero, the transfer rate can be increased from an initial rate of 10 L/hr to fill the liquid helium container. The level is maintained by inspecting daily and refilling before it reaches the 40% mark. Special procedures are followed to ensure that the hot gas in the helium transfer tube does not evaporate the liquid in the cryostat.

GEO-CENTERS also supported the preparation and characterization of superconducting thin films in the NRL Thin Film Deposition Facility. Each cycle to prepare thin films for research involves the following basic steps: insert the sample into the chamber; pump a vacuum on the chamber overnight; deposit the film; cool for one hour in 100 torr O<sub>2</sub> atmosphere; purge the chamber with nitrogen; remove the sample. The system is operated from a control rack containing power supplies, vacuum system and gas flow valve controllers, the substrate temperature controller, and ion and convection vacuum gauges. The vacuum system contains of two Edwards and Alcatel two-stage roughing pumps and Varian and Edwards diffusion pumps. Thin films of such magnetic oxide materials as CaMgO<sub>3</sub> and LaMnO<sub>3</sub>, were prepared on various substrate materials such as MgO, SrTiO<sub>3</sub>, or LaAlO<sub>3</sub>. The film thickness was measured with a Tencor Alpha Step 100 instrument after applying resist and etching part of the film away with HCl solution.

GEO-CENTERS also supported NRL in the installation of a new Pulsed Laser Deposition Facility. We installed fluorine gas lines and fabricated a gas flow system that includes stainless

steel tubing and fittings, control valves, and mass flow controllers. We also assisted in the assembly and set up of the deposition chamber, shown in Figure 2, by machining chamber port blanks, silver soldering, and machining parts, as required. In addition, we installed peripheral equipment and used the Alcatel ASM 110 turbo CL leak detector to find leaks in the vacuum system.

GEO CENTERS has supported all of the above film deposition and magnet facilities by ordering and storing materials and supplies, maintaining chilled water, vacuum, cryogenic material, and gas systems and by providing assembly, installation, and machining services. As needed, we have provided a skilled operator of the equipment in the NRL Bldg. 3 Room 182 machine shop, including milling machines, lathes, saws, drill presses, a sheet metal shear and brake, a sandblaster, and a 75-ton hydraulic press.



**Figure 2. Vacuum chamber of the pulsed laser deposition system.**

#### **2.4 CLEAN ROOM SUPPORT**

GEO-CENTERS provided expert technical support to NRL Code 6340 clean room operations in Building 3 (Figure 3). There, we developed and tested new fabrication procedures for ultra thin films on a variety of substrates using innovative, cutting edge lithographic patterning and materials deposition techniques. Our senior clean-room technician was involved in the development of specialized, thin film devices with very fine (sub-micron) structure widths. This work involved the operation of mask aligners, E-beam and UV lamp developers, various deposition systems including thermal evaporators, the sputtering, pulsed laser deposition (PLD), Matrix Assisted Pulsed Laser We also supported the NRL Materials Physics Branch's Transport and Electronic Structure group by developing and testing processes to fabricate hybrid Hall

Effect structures and magneto-electronic devices using photo resist patterning. We have experimented with various types and combinations of resist coating, alignment, developer, etcher, and lift off designs in support of new biomedical sensor development. By covering specific magneto-electronic elements with a thick, metal, patterned film to produce a "standoff," specific sensors can be effectively shielded from the magnetic fields that are produced by magnetic microparticles, i.e., by increasing the separation between the particles and the sensors. The requirements to do so include the following: (a) the standoff distance must be well defined and localized over specific sensors, (b) the separation must be 0.5 microns thick or greater, and (c) the standoff must be compatible with the surface chemistry that is later applied to the biosensor chip.

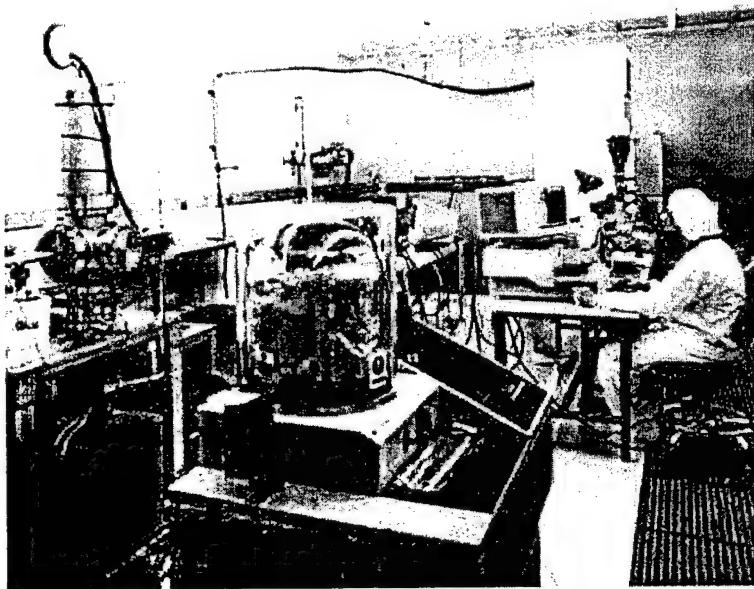


Figure 3. NRL Building 3 Clean Room.

Other typical work under this contract has involved efforts developing optimal etching techniques for submicron patterns produced by E-beam lithography writing. Optimized techniques include the right combination of gases in the reactive ion beam plasma etcher to produce a reasonable etching rate, a good vertical etching profile, a clean etching surface, and uniformly defined etching areas.

We have used a Karl Suss mask aligner to lay down fine patterns for NRL's specialized circuit development projects. After applying and spinning the layer of polymethyl methacrylate (PMMA) on the substrate, the positive or negative resist pattern was exposed with the AOI deep UV flood lamp. The deep UV light was needed to expose the pattern and still provide the desired deep undercutting of the resist. Alternately, the Joel E-beam lithographic developer was used with other resists when finer (sub-micron) features were being imaged. Results were evaluated by SEM.

GEO-CENTERS also used the Matrix Assisted Pulsed Laser Evaporation (MAPLE) and the Pulsed Laser Evaporation (PLE) systems to create very thin films by evaporating the source metal. The pulsed laser deposition lab uses two Lambda Physik LPX 305I KrF excimer lasers to evaporate the source material, which is then deposited on the target substrate. The MAPLE process requires the following conditions:

- A clean surface acoustic wave (SAW) resonator that has been tested before being placed in the MAPLE system, and measurement of the SAW's frequency at the start and end of the MAPLE processing. The difference between the two frequencies determines the thickness of the deposited film.
- Target preparation: mix the polymer and solvent, then freeze before using.
- Vacuum chamber temperature down (-190 °C).

The developed resist was then removed using dry etch methods such as reactive ion beam etching. GEO-CENTERS personnel used several different chambers and techniques to achieve the best results. Our senior technician selected the best ionizing gas to etch the desired material. Commonly used gases included O<sub>2</sub>, CF<sub>4</sub>, and CHF<sub>3</sub>. Finally, the protective resist layers were removed using solvents such as acetone.

### **3.0 TESTING AND EVALUATION OF ADVANCED MATERIALS**

#### **3.1 CORROSION TESTING**

Life Cycle engineering requirements for seawater applications have stressed the need for increased maintenance cycles and ultimately have resulted in the selection and implementation of advanced technology hull and piping materials. Concurrent with the introduction of these new materials, there is the necessary requirement for protection from electrolytic corrosion by use of cathodic protection (CP) and/or protective coatings systems. To evaluate the suitability of these new materials and coatings for shipboard use, physical testing of these materials in the actual or prototypical environment is required. GEO-CENTERS has applied our broad based understanding of electrochemical properties of materials, engineering design, and analysis to support NRL in the RDT & E of these new materials for use on naval platforms. Examples of specific projects are discussed below.

GEO-CENTERS supported NRL in developing in-situ electrochemical sensors, which are capable of evaluating the integrity of coatings and CP systems in seawater and compensated fuel ballast tanks at considerable cost savings to the Navy. An associated analysis program was developed to process the sensor data and ultimately provide Port Engineers with a quantitative methodology for determining the integrity of the tanks' coating/CP system and a decision path process for deciding necessary tank maintenance. GEO-CENTERS has supported NRL in the

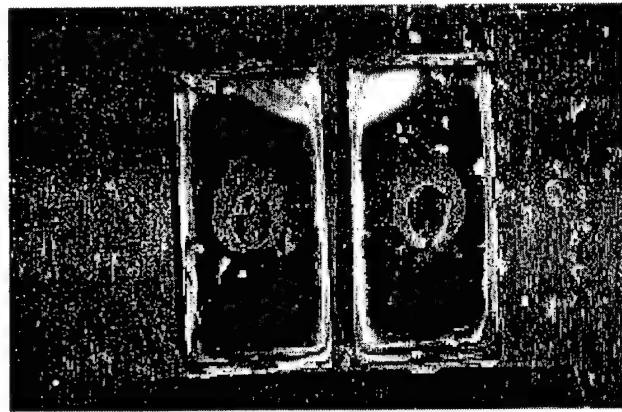
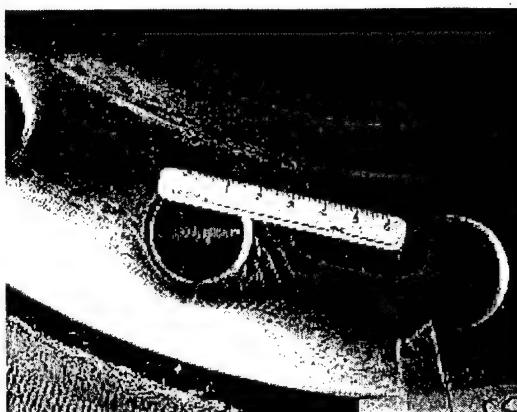
design, fabrication, installation and data analysis of the prototype sensors in thirty-two tanks on eight Navy ships, listed in the following table.

<b>Ballast Tank Corrosion Sensors Current Ship Installations</b>		
<b>Ship</b>	<b>Date</b>	<b>Number of tanks</b>
USS Portland LSD-37	February 1997	4
USS Rushmore LSD-47	May 1997	4
USS Wasp LHD-1	January 1998	4
USS Tortuga LSD-46	February 1998	10
USS Saipan LHA-2	February 1998	4
USS Kinkaid	DD-965	1
USS Comstock LSD-45	January 1999	4
USS Oldendorf DD-972	July 1999	1

GEO-CENTERS also provided support in the design of Impressed Current Cathodic Protection (ICCP) systems, using the physical scale modeling (PSM) technique. These systems require the critical placement of anodes and reference electrodes so that sufficient current density reaches areas that are most difficult to protect. PSM was used as a primary tool in determining the placement of anodes and reference cells components, in order to achieve uniform and protective hull potentials. Scale models, in linear scaled resistivity electrolyte, were used to provide important information on inter-zone relationships, geometric factors, static/dynamic current behavior and galvanic influences. GEO-CENTERS fabricated and instrumented the models and conducted the model testing at the designated Navy PSM facility.

GEO-CENTERS conducted research to evaluate the electric field (EF) produced as a result of the ICCP system. A miniature EF sensor was designed, fabricated and is being used in conjunction with the ICCP PSM studies. The ICCP system on the models are adjusted and balanced to modify the EF signature behavior, while concurrently maintaining acceptable corrosion control. Presently, alternative boundary (BEM) and finite element (FE) computer models for ICCP and EF evaluation are unable to quantify the many independent and changing variables found in an actual CP system. With PSM, however, the ICCP and EF data are being utilized to provide essential input for the development and verification of an accurate computer model.

We have also conducted both basic electrochemical research and materials exposure testing in an attempt to define the mechanism of crevice corrosion initiation/propagation of high strength nickel (Ni) alloys in seawater. Significant testing was performed by GEO-CENTERS at NRL Key West concerning the initiation of crevice attack in these alloys. Current efforts include analysis of the long-term life-cycle performance of alloy 625, with alloy C276 weld overlay, under operational pressure regimes and measurement of the performance of alloys 625 and C276 in chlorinated/dechlorinated seawater, as illustrated in Figure 4.



**Figure 4. Crevice attack at O-ring (left) and crevice attack on Alloy 625 at metal/metal interface (1 year).**

Other related work has addressed the crevice solution chemistry of alloy 625 and the possible effects of alloy microstructure and ennoblement on crevice initiation and attack. GEO-CENTERS personnel are presently studying crevice corrosion behavior of eight Ni alloys. Electrochemistry studies were conducted using Princeton Applied Research Potentiostats/Galvanostats and CorrWare™ software. In conjunction with the crevice studies, numerous polysulfide compounds were evaluated for use as an in-situ countermeasure for the repair of crevice corrosion attack, recently discovered at heat exchanger seal surfaces.

GEO-CENTERS also designed and fabricated dockside chlorination units for use in submarine bio-fouling control of the ASW seawater systems and studied the high temperature effects on the adhesion and durability properties of Silicon "easy release" anti-foulant coatings for use in heat exchangers.

Our support of NRL Corrosion programs under this contract has been documented in detail in the following publications and reports:

K.E. Lucas, P.F. Slednick, E.A. Hogan, E.D. Thomas, and A.I. Kaznoff, "Comprehensive Monitoring and Evaluation of Ballast Tank Coatings Integrity for Life Prediction and Condition Based Maintenance," Corrosion 00, Orlando, FL, March 1999.

K.E. Lucas, E.D. Thomas, A.I. Kaznoff, and E.A. Hogan, "Design of Impressed Current Cathodic Protection (ICCP) Systems for U.S. Navy Hulls," in Designing Cathodic Protection Systems for Marine Structures and Vehicles, STP 1370, H. P. Hack Ed., American Society for Testing and Materials, West Conshohocken, PA., 1999.

K.E. Lucas, P.F. Slednick, E.D. Thomas, M..F. Evans, and E.A. Hogan, "Evaluation of Seawater Ballast Tank Coating Integrity Using Remote Monitoring Sensors and Inspection Technology," presented at ASNE 98, Crystal City, VA, 1998.

K.E. Lucas, M.A. Evans, E.A. Hogan, and E.D. Thomas "Criteria for the Design of Impressed Current Cathodic Protection (ICCP) for NSSN Seawater ballast Tanks," Tri-Services Conference Proceedings, November 1997.

K.E. Lucas, E.A. Hogan, E.D. Thomas, P.F. Slebodnick, and A. Seelinger, " USS Virginia Ballast Tank Connector Qualification Study," November 1999.

K.E. Lucas, E.A. Hogan, and E.D. Thomas, "Evaluation Of Cathodic Protection Requirements For The SSN 23 "Genesis" Hull Using Physical Scale Modeling," September 1999.

K.E. Lucas, E.A. Hogan, and E.D. Thomas, "Design of an Impressed Current Cathodic Protection (ICCP) System for an MCM Class Hull," September 1999.

K.E. Lucas, M.A. Evans, E.D. Thomas, P.F. Slebodnick, and E.A. Hogan, "Design Criteria for Seawater Ballast Tank Impressed Current Cathodic Protection (ICCP) Systems," NRL/MR/6310-98-8170 (1998).

K.E. Lucas, M.A. Evans, E.A. Hogan, and E.D. Thomas, "Evaluation of a Zinc Cathodic Protection System for Universal Modular Mast (UMM) Components and Sail Structure Using Physical Modeling," NRL/MR/6310-98-8169 (1998).

K.E. Lucas, E.D. Thomas, and E.A. Hogan "Results of 1-Year Performance Testing of Galvotec™ Alloys Inc. Aluminum Anodes Under MIL-A-24779," NRL Letter Report, January 1998.

K.E. Lucas, E.D. Thomas, P.F. Slebodnick, and E.A. Hogan, "Evaluation of High-Strength Fastener Materials for the Replacement of Monel K-500 in Seawater - Final Report," NRL Memorandum Report NRL/MR/6310-97-8121 (1997).

K.E. Lucas, M.F. Evans, E.A. Hogan, and E.D. Thomas, "Evaluation of a Zinc Cathodic Protection System for Universal Modular Mast (UMM) Components and Sail Structure Using Physical Modeling," NRL Letter Report, September 1997.

K.E. Lucas, M.A. Evans, E.A. Hogan, and E.D. Thomas, "Criteria for the Design of Impressed Current Cathodic Protection (ICCP) for NSSN Seawater Ballast Tanks," NRL Letter Report, March 1997.

### 3.2 COATING LABORATORY SUPPORT

GEO-CENTERS Key West Group worked closely with NRL to develop a state-of-the-art Coatings Test Laboratory operated in conjunction with the NRL Marine Corrosion Facility. Our coatings technical staff was involved with the establishment of this facility and the procurement, installation, and operation of all its associated test equipment and instrumentation including the following:

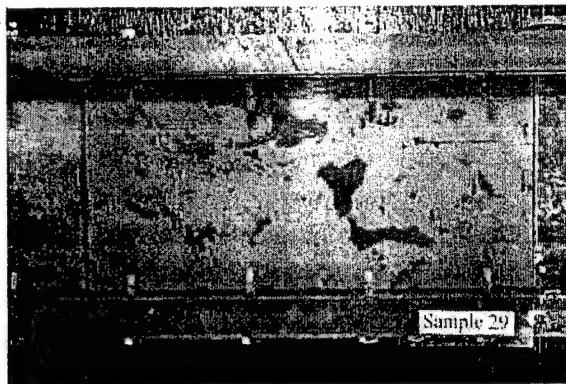
- Solvent Recovery walk-in Spray Booth, w/ Vapor Trap and Solvent Collection System
- Large Blast Cabinet, w/ dust Collection, Filtering and media Recycling System
- HVLP and Reg. Spray System
- CCD Stereomicroscope
- X-Rite and Hunter Color Spectrophotometer
- Leneta Anti-Sag Meter
- Dry and Wet Film Thickness Gauges
- 60 Degree Gloss Meter and Gloss Standards
- Q-Panel Salt Fog Cabinet ASTM B117 & GM9540P/B 2
- Atlas Xenon Weatherometer
- Q-Panel Condensation Chamber, ASTM 4585
- Q-Panel Ultra-Violet/Condensation Weather Cabinet, ASTM G-63 and D-4587
- Stormer Viscometer
- Blast Standards and Media Standards

Associated familiarity and testing per specification was performed by the GEO-CENTERS staff to the requirements of: MIL-P-24441, MIL-E-24635, MIL-P-24647, DOD-E-24607, TT-P- 645, MIL-E-24763, DOD-P-23236, MIL-P-24667, MIL-A-23262. We also performed testing as per the Naval Standard Technical Manual (NSTM), ASTM, DOD, EPA, Steel Structures Painting Council (SSPC), and the National Association of Corrosion Engineers (NACE) standards. Atmospheric testing/exposure of coatings test panels was in accordance with ASTM D4141 & D1014. GEO-CENTERS staff also supported coating application, HAZMAT procedures, VOC compliance, coatings formulation chemistry, manufacturer spray technique, SSPC surface preparation techniques, coating properties evaluation per accepted ASTM procedures and NACE basic corrosion evaluation.

GEO-CENTERS provided support to Navy programs designed to address certain maintenance-related problems. Examples are the environmental testing of the Silicone Easy Release Antifoulant coatings and the new high solid edge retentive coatings system for shipboard tanks and voids. The testing of silicone based coatings required a fouled coated panel to be tested under flow conditions to ascertain its release properties. GEO-CENTERS personnel provided the necessary flow trough operation and video documentation and analysis of flow performance to enable the screening of the candidate coatings materials as illustrated in Figure 5.



*Low Flow Condition*



*Increased Flow Condition*

**Figure 5. Flow trough-tested fouled coatings.**

To environmentally test the durability of edge retentive coatings, GEO-CENTERS assisted in design, fabrication and instrumentation of an alternate immersion test tank for exposure of coated T-beams and I-beams. As new edge retentive coatings were developed, additional beams were prepared, coated and the samples placed into the trough for long-term exposure testing. Many of the coatings programs are ongoing due to the continual resurgence of newly formulated coatings. GEO-CENTERS also evaluated underwater applicable epoxies, powder coatings, high solid coatings, surface tolerant epoxies and Low Solar Absorption (LSA) non-skids and epoxies. GEO-CENTERS provided specimen preparation, coating application, laboratory property testing and environmental exposure testing for a variety of new coatings and application technologies of interest to the Navy.

### 3.3 METALLURGICAL ANALYSIS

An EA-6B Outer Wing Panel (OWP) teardown analysis was conducted to verify predicted fatigue life values for the EA-6B aircraft. The EA-6B OWPs that were chosen for this analysis were fatigue test articles, circa 1970. The OWPs were production-representative, and sustained 9000 spectrum flight hours during testing. After the test, the OWPs were placed in Grumman's storage yard (Bethpage, NY) until they were retrieved in 1996 (25 years). GEO-CENTERS supported the Naval Research Laboratory (NRL) in conducting the metallurgical analysis, including determination of magnitude and location of fatigue cracking and corrosion damage.

The data presented in this report was reported in detail to the NAVAIR sponsor as an NRL report. Although the technique and methodology of the metallurgical analysis reported will be presented here, the detailed summary of findings and collection of sketches of significant fatigue cracks will not be repeated. In the following paragraphs, discussions of the reporting format for crack data refer to sections in the previous report.

NRL has been working with the Naval Air Systems Command (NAVAIR) and the Naval Air Station (NAS) at Jacksonville, FL. Once the EA-6B OWP's for this exercise were identified, small sections were removed by Grumman for analysis. After the panels were disassembled and the fasteners removed, the fastener holes were carefully cleaned. NRL requested that removal of metal be limited to 0.002 inch from the radius of each fastener hole. Non-destructive inspection of the fastener holes was performed at NAS Jacksonville prior to crating, and shipping of the components.

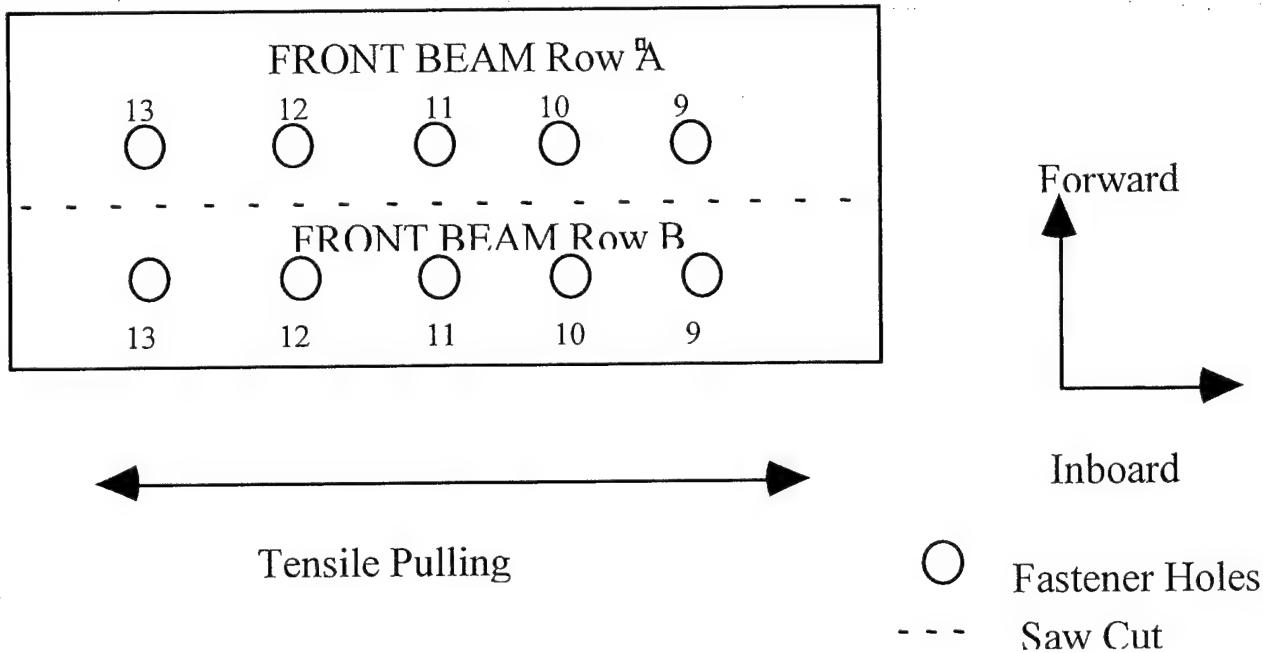
The enumeration plan used followed the standard procedure of first identifying the various regions and second numbering the holes sequentially from inboard to outboard and forward to aft.

In addition to the primary fastener holes, several others were also accounted for and evaluated for signs of fatigue or corrosion. Nut-plates are generally attached to the skin with two nuts, producing a smaller hole on either side of the primary fastener hole; these are labeled A and B (i.e., Hole 9 in Inboard Flaperon Bell Crank Access has a nut plate, the forward nut hole is labeled 9A, the primary fastener hole is 9, and the aft nut hole is labeled 9B.)

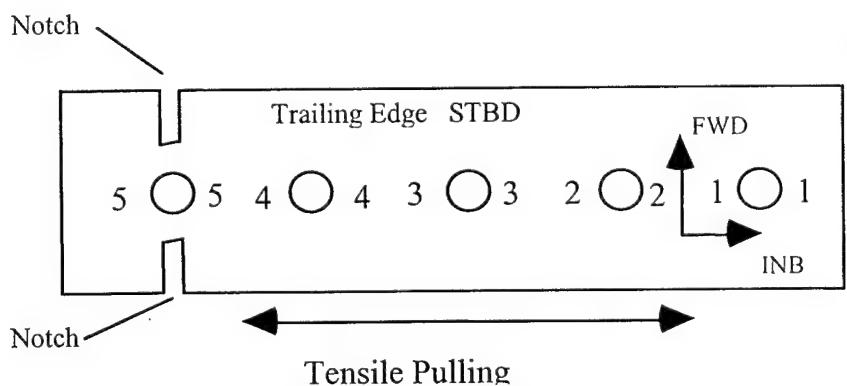
Once the outer wing panels were received, they were inventoried and cut into sections that could easily be handled in the laboratory where they would be mechanically opened. During the course of the evaluation, the panels were reduced to specimens the size of postage stamps. Each small piece, having either one or two exposed fracture surfaces, was numbered and the orientation of the component in the fuselage structure was indicated directly on the sample. Each specimen was stored in a polyethylene bag that was meticulously labeled with component names and fastener hole numbers.

The first step of the fatigue evaluation involves sawing strips of holes from the outer wing panels, or cutting sections of the panels, so that a single line of holes is isolated. These holes are aligned along the direction of expected loading for each component, which was directed by NAS Jacksonville. The load path is in the inboard to outboard direction (Figure 6). In the laboratory, notches are cut with a band saw on either side of the first fastener hole in any series. The notches provide a stress concentration and weaken the strip in a very specific plane. When the entire strip is pulled in tension, tensile overload fracture is most likely to initiate at the notch tips, opening the first fastener hole in the series at its midpoint (Figures 7 and 8). Subsequently the second in the series is notched and opened, and so on.

If a fatigue crack had previously developed at the notched fastener hole, it will serve as the initiation point for the tensile overload fracture because the crack tip is much sharper than the machined notch and is therefore a more effective stress concentrator.

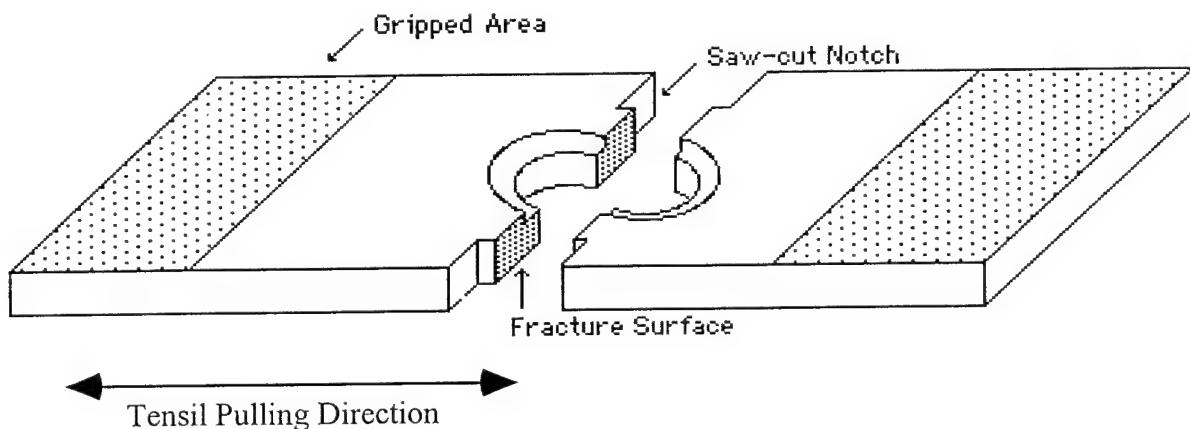


**Figure 6.** The evaluation procedure involves sawing strips of holes from the outer wing panels. The orientation of the strips is in the direction of flight loads, usually inboard to outboard.

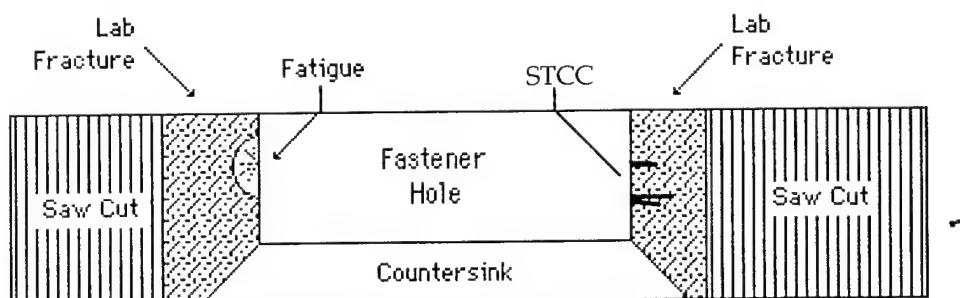


**Figure 7.** Notches are cut into each side of a fastener hole before it is opened in a tensile testing machine. This specifies the plane of fracture.

The resulting fracture surfaces of each hole, (Figure 9) are studied under a binocular microscope at thirty magnification to determine whether fatigue cracks were present before the sample was mechanically opened. The fatigue cracks appear as relatively flat, semi-elliptical zones on the fracture surface adjacent to the holes, usually appearing dramatically different from the ragged, steeply-inclined tensile overload fracture surfaces produced while breaking the strips (Figure 9).



**Figure 8. Strips of holes are pulled in a tensile testing machine to break open each hole in the strip. A fracture surface is produced having the same orientation as a potential pre-existing fatigue crack.**



**Figure 9. The fracture surfaces of each hole are studied under a binocular microscope at thirty power to determine whether fatigue cracks were present while the outer wing panels were in test. The fatigue cracks appear as relatively flat, semi-elliptical zones.**

When fatigue cracks are identified, they are measured using a filar eyepiece in the binocular microscope, and their dimensions are recorded in a notebook. The notebook pages are labeled at the top with the name of the part being inspected. The numbers of the fastener holes are on the left of each line. Holes which have not yet been inspected have no notations. Holes which were inspected and show no evidence of cracking are indicated by a "+". The general format of the recording for fatigue cracks is DXW ORIENTATION, where D is the depth of the crack into the material from the bore of the hole in thousandths of an inch (mils) and W is the width of the

crack parallel to the axis of the hole in the same units. **ORIENTATION** indicates which side of the hole the defect was found (forward or aft). For Short Transverse Corrosion Cracks (STCC), an estimate is made as to the maximum depth into the fracture surface that the corrosion extends and this is denoted by: **STCC DEPTH ORIENTATION**. **MAX** indicates that there are several STCC and that the longest one is measured and noted. In the case of small cracks, the thirty power inspection is insufficient to identify fatigue with certainty. For the purposes of this study, a crack size of 0.005 inch was selected as the size below which a determination of cracking morphology would not be made. In many cases of very small features, it is difficult to determine whether that which is observed is a flaw which existed prior to the teardown or is a shiny edge resulting from shearing during mechanical opening in the analysis. Such features were recorded as a small crack with the symbol <5. These findings were summarized in Section B of the failure analysis report, not repeated here.

In cases where the fatigue or corrosion damage measures 5 mils or greater, a schematic was drawn on standardized sheets. These sheets illustrated the type of hole configuration, the difference being the extent of the countersink into the hole. When a crack was found, it was sketched and its dimensions recorded.

### 3.4 SURFACE PREPARATION TOOL ANALYSIS

GEO-CENTERS supported the NRL Center for Corrosion Science and Engineering in its program to provide improved hand tools to the Navy to improve the efficiency and reduce the time required by sailors and marines to maintain their ships. Objectives of this program were to:

- Evaluate and select commercial hand tools for paint removal/surface preparation.
- Define by ship class a recommended listing of tools required.
- Develop and deploy a prototype transportable tool depot, for use and evaluation during ship availabilities.

The tool depot developed under this program was equipped with the following contents:

- Chipping Hammers
- Grinders and polishers (various types)
- Needle scalers (3 types)
- Tile strippers
- Walk-behind deck crawlers
- Pressure washers

- HEPA vacuums (2 types)
- Consumable supplies for all the above tools

Support was also provided for developing an inventory control system for tracking tool check-out and check-in, tool use and reliability, and use of consumables.

#### **4.0 APPLICATIONS ENGINEERING AND SYSTEM DEVELOPMENT**

The primary requirement of the Materials Science and Technology (MS&T) Division of the Naval Research Laboratory is to investigate emerging technologies for the ultimate application of these technologies as practical products in the fleet. To demonstrate the practicality and viability of these developing technologies, the Naval Research Laboratory tasked GEO-CENTERS to provide engineering support in the areas of ship and submarine hull, mechanical, and electrical engineering (HM&E). Extensive engineering support has been provided in the areas of: system and subsystems design, producibility studies, standardization, reliability and maintainability analyses, integrated logistics support, test and evaluation, shipboard installation support, drawing preparation and review, modeling and prototyping, configuration management, and specifications and standards.

Over the course of the contract the two principal focus areas for application engineering were Shipboard Solid Waste Disposal and Shipboard Liquid Waste Concentration and Disposal. Under the first focus area, Shipboard Solid Waste Disposal, GEO-CENTERS engineers and technicians provided application engineering support to three programs: Submarine Plastic Waste Management, Solid Waste Equipment Production and Life Cycle Support, and the Plasma Arc Waste Destruction System (PAWDS) program. Under the second focus area, Shipboard Liquid Waste Concentration and Disposal, engineering support was provided to three additional related programs: Oily Waste Concentration and Compensated Fuel Ballast Tank Model, Graywater Concentration, and Vortex Incinerator.

The following paragraphs summarize the activities completed under each of the six programs listed above. The summaries consist of a brief narrative of each program with a chronological listing of the accomplishments.

##### **4.1 SHIPBOARD SOLID WASTE DISPOSAL**

###### **4.1.1 Submarine Plastic Waste Management**

The National Defense Authorization Act for Fiscal Year 1994 prohibits the discharge of plastic waste from U.S. Submarines after December 31, 2008. This has required the Navy Submarine community to develop an effective method of handling and storing plastic waste aboard ship for eventual disposal in port.

The retention of plastic waste on board submarines presents three problems. The volume of plastic waste to be stored must be reduced, the waste must be packaged to eliminate odors, and acceptable storage locations for the waste must be identified. GEO-CENTERS engineers working with engineers at the Carderock Division of the Naval Surface Warfare Center (NSWCCD) conducted a review of all potential plastic waste management options. Seventeen potential processes were identified for treating, cleaning, monitoring or reducing the volume of plastic waste. When these seventeen processes were compared against known submarine design constraints, it became clear that the combination of the existing and unique submarine trash compaction unit and the concept of an odor barrier bag developed for the surface ship plastic waste processor was the most practical solution. The Navy and GEO-CENTERS developed a process whereby plastic waste was compacted directly into an odor barrier bag that was renamed the "submarine plastic waste containment bag."

Testing of both Ohio and Los Angeles class trash compaction units showed plastic waste volume reductions of 27 and 21 to one, producing a manageable level of approximately one can or cylinder of plastic waste per mission day per ship. Also, because of the high compaction forces required, a stronger odor barrier bag than those used on surface ships had to be developed. Numerous plastic manufacturers were contacted and ultimately a 10-mil-thick product consisting of linear, low-density polyethylene, nylon and EVOH emerged as the most effective from a cost and performance standpoint.

Working with Newport News Shipbuilding, engineers from NSWCCD and GEO-CENTERS were able to develop a suitable compacted plastic waste storage area on Los Angeles class submarines. The storage area required a modification to remove the sanitizing sink in the wardroom pantry and install a storage locker. This was investigated with a mockup in the laboratory and ultimately demonstrated at sea via TEMPALT aboard two deployed submarines. On the Ohio Class submarines, empty dry provision storage modules have been nominated for compacted plastic waste storage. The plastic waste compaction procedure and storage area has been demonstrated aboard deployed Ohio Class boats with great success.

In summary, the research and development team identified a simple and effective solution for processing and storing plastic waste onboard submarines. The combination of existing trash compaction units, tougher odor barrier bags and a well planned compaction procedure minimizes the impact of storing plastic waste by significantly reducing the volume, eliminating odors, and maximizing storage capability.

#### Submarine Plastic Waste Management Accomplishments

- November 20, 1997: Attended Submarine solid waste program briefing in GEO-CENTERS offices. SEA03R , NSWCCD, SEA92TE and PMS 450 attending.
- December 4, 1997: Reviewed potential solutions and technologies for use of abrasion-resistant odor barrier bags for use as trash disposal unit (TDU) can overwraps.

- February 2, 1997: Met with DuPont Company representatives s to discuss improved formulations and manufacturing techniques for stronger odor barrier bags.
- April 30, 1998: Completed design of full sized pantry mockup for an SSN 688 TDU storage compartment, forwarded to Newport News for review (see Figure 10).

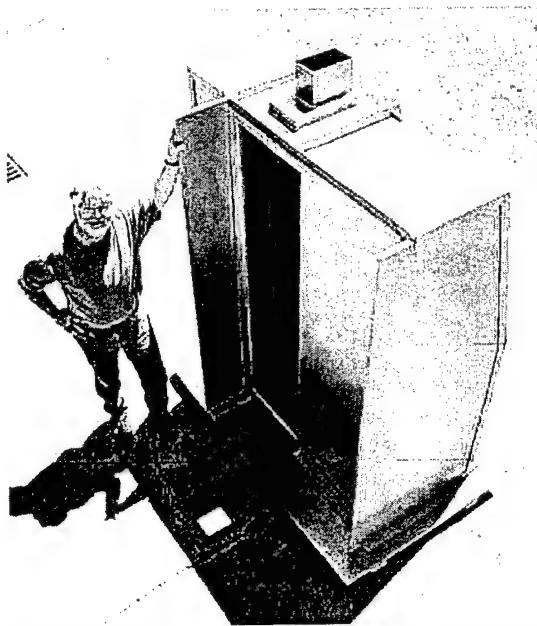
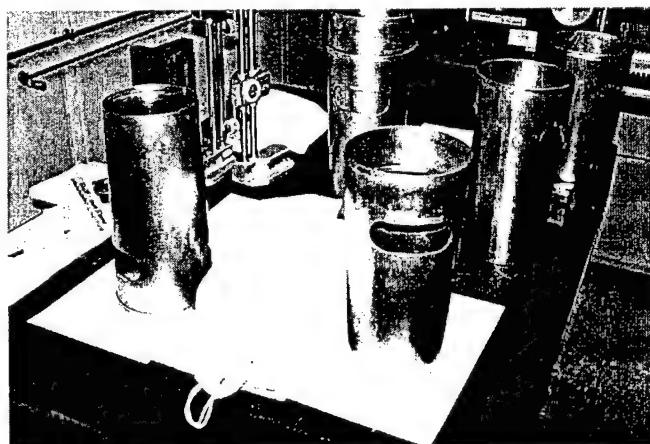


Figure 10. SSN 688 plastic waste storage mock-up.

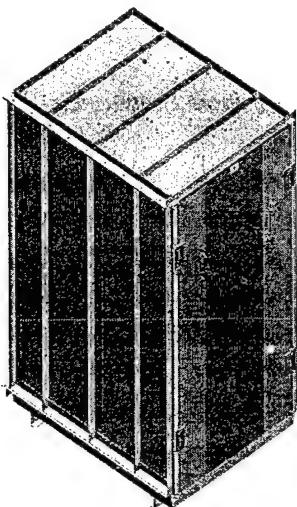
- May 31, 1998: Mockup of full sized pantry TDU can storage area fabricated and shipped to NSWCCD.
- May 31, 1998: Completed design of pantry under-the-counter TDU can storage area mock-up and sent to Newport News for review.
- May 31, 1998: Contacted 54 companies to determine if they have off-the-shelf or could manufacture a substitute compaction vessel for the TDU can itself.
- June 30, 1998: Fabricated and shipped to NSWCCD the SSN 688 under-the-counter TDU can storage area mock-up.
- June 30, 1998: Placed purchase orders for completion of DuPont recommended formulation of odor barrier bags using a combination of DuPont Surlyn with a laminated layer of DuPont Tyvek for strength.
- July 31, 1998: Submitted to NSWCCD a draft test plan for conducting a plastic waste generation survey aboard an underway SSN 688.

- August 31, 1998: Submitted to NSWCCD a draft guide for submarine solid and plastic waste management.
- October 31, 1998: Developed a data collection test booklet for the USS CHEYENNE (SSN 773) and USS MONTPELEIR (SNN 765) describing the data to be collected during the solid and plastic waste onboard study.
- November 9, 1998: Developed and submitted to NSWCCD a Plastic Waste Compaction Procedure Quick Reference Card for use by operators when compacting plastic waste into Submarine Plastic Waste Containment Bags.
- December 31, 1998: Developed and produced detail drawings of a downsized pre-pack garbage can. Completed purchase order to fabricate 6 downsized cans for use on demonstration submarines.
- January 31, 1999: Delivered to NSWCCD Laminated copies of submarine Quick Reference Cards for Plastic Waste Compaction Procedure and Heat Sealer operation.
- January 31, 1999: Developed and delivered to NSWCCD two viewgraph presentations describing the Submarine Plastic Waste Management Demonstrations.
- February 28, 1999: Delivered 6 pre-pack garbage cans to NSWCCD (see Figure 11).
- February 28, 1999: Produced and delivered to NSWCCD first draft of paper describing Navy Submarine Solid Waste R&D Program entitled "It's in the Bag: Submarine Plastic Waste Management."
- March 1, 1999: Developed a draft Submarine Solid Waste Management Guide for NSWCCD.



**Figure 11. Submarine Waste Pre-Pack Cans.**

- April 30, 1999: Assisted NSWCCD personnel in training 4 crewmembers from USS MONTPELIER in Plastic Waste Management System procedures and Demonstration Study data collection requirements.
- May 4, 1999: Visited USS MONTPELIER (SSN765) at Norfolk Naval Base to assist in installing equipment and consumables for Plastic Waste Management Demonstration.
- Fabricated support bar and brackets and shipped to Pearl Harbor, HI for use on USS TUCSON (SSN 770).
- May 10, 1999: Visited USS TUCSON at Pearl Harbor Naval Base to assist in installing equipment and consumables for Plastic Waste Management Demonstration and to conduct crew training.
- June 1999: Designed taller pre-pack garbage cans with external handles for use on SSBN 726 Class demonstration submarines.
- June 1999: Investigated naugahyde as a potential curtain material for SSBN 726 Class Plastic Waste Storage Module.
- July 1999: Designed a steel mockup of the food stowage module.
- August 1999: Shipped pre-packed garbage cans to NSWCCD.
- August 1999: Fabricated the steel mockup of the SSBN 726 Plastic Waste Stowage Module. Shipped to NRL Chesapeake Beach Division for fire testing.
- Designed and prepared drawings for a self-closing door for use on SSBN 726 Class Stowage Module.
- September 1999: Designed and fabricated 16 cover plates and 32 battens for use on SSBN 726 Class dry provision storage module.
- October 1999: Shipped 8 batten plates to USS MARYLAND (SSBN 738) for use in Plastic Waste Stowage module.
- October 1999: Completed fabrication of self-closing storage module bi-fold door and demonstrated it for NSWCCD (see Figure 12).



**Figure 12. SSBN 726 Plastic Waste Stowage Module.**

- October 1999: Completed first draft of paper “Plastic Waste Management Demonstration on the LOS ANGELES Class” for presentation at the 26<sup>th</sup> Environmental Symposium and Exposition in Long Beach, CA.
- Updated drawings and shipped to NSWCCD the self-closing stowage module bi-fold door for evaluation and fire tests.
- January 2000: Specified and ordered a roll up door to be installed on OHIO Class Submarine Plastic Waste Stowage Module.

#### **4.1.2 Solid Waste Equipment Production and Life Cycle Support**

The U.S. Navy developed a comprehensive solid waste management program to comply with the “Act to Prevent Pollution from Ships” (Title 33 United States Code Chapter 33) which ratified the “International Convention for the Prevention of Pollution from Ships” (MARPOL 73/78). To accomplish this program the Navy implemented aggressive acquisition plans to procure and install solid waste processing equipment onboard Navy ships. Plastic Waste Processor (PWP) ship installations are now complete and some of these units are entering their overhaul phase. Large and small pulpers and metal glass shredders (MGS) are currently in their installation phase. GEO-CENTERS was instrumental on the Navy’s original acquisition team by participation on the design of this equipment. Our involvement continued through this contract with our validation of the preliminary designs for pulpers and metal-glass shredders and by providing assistance during their initial production and installation. We also developed an interim facility to maintain the plastic waste processors and make improvements to their life-cycle performance.

In parallel with the Navy's production bid solicitation for pulpers and metal-glass shredders, GEO-CENTERS fabricated and assembled pre-production units to validate the preliminary drawings and finalize the design to achieve production level drawings. As issues arose related to manufacturability or reliability of the pulper preliminary designs, Navy permission was obtained to modify the pre-production units to improve the design as needed. Consequently, our pre-production units effectively incorporated these revisions which were documented into a final set of as-built drawings. This final drawing set with 71 revisions was then provided to the Navy for incorporation into the production contract awards, thereby eliminating a number of potential production and life cycle issues. One notable change that was factored into this drawing package included adding a flash chromium plating to the pulper drive shafts to eliminate the potential for galling with the impeller threads. Another parallel GEO-CENTERS effort during the solicitation period was to combine two castings on the small pulper slurry chamber into one casting. During the preliminary design phases it was initially believed that these castings could not be made as a single casting due to their complexity. However, during the validation phase, GEO-CENTERS engineers worked with several foundries to develop and validate a producible one-piece casting design that saved significant manufacturing time during production.

The validation of the pulpers resulted in additional benefits to the Navy and its production contractors. One each of the large and small validation pulpers was sent to each of the production contractors soon after contract awards. These Government furnished units became the pattern used by the contractors to build their production units, which helped to assure that the Navy would receive final units as designed. Navy and GEO-CENTERS personnel also used these units when training the contractors on the proper operation and testing of completed units. At Government kick-off meetings with the production contractors, GEO-CENTERS engineers presented lessons-learned from manufacture of the validation units to transfer knowledge of fabrication processes and special fixtures. Also foundries and patterns for critical castings developed by GEO-CENTERS during validation were utilized by a production contractor to help meet the necessarily aggressive production schedule. GEO-CENTERS test procedures were utilized to develop the Navy's Critical Inspection & Verification Plan, which was incorporated as a requirement into the production contracts. Our logistics knowledge became the basis for the Technical Manuals, and the Contract Spares Lists and Packaging Procedures which were also incorporated into the production contract.

Utilizing our knowledge of pulper fabrication, the Navy tasked us with developing additional pre-production pulpers to meet the aggressive ship installation schedule. We fabricated two large pulpers and metal-glass shredders for installation on two new ships, DDG 73 and LHD 6, plus two additional large pulpers for the Naval Surface Warfare Center, Carderock Division, for testing and potential foreign military sales. Due to the tight quarters on the DDG 73, GEO-CENTERS assisted the Navy and shipyard personnel at Bath Iron Works with the teardown and re-assembly of the large pulper installation onboard this ship. We documented the knowledge gained from this installation and incorporated it into a draft revision of the technical manual for future DDG installations.

GEO-CENTERS has also assisted with interim management of Navy auxiliary spare parts by receiving and recording the inventory of over 10,000 pulper and shredder parts without NSNs. These parts were ultimately used to assemble shipsets of pulpers and metal-glass shredders for seven recommissioned ships. We provided engineering, drafting, technical and integrated logistics to help determine the requirements for operating a facility for maintaining and improving the life cycle performance of plastic waste processors installed in the fleet. We established an inventory of rotatable pool parts made from refurbished items from installed PWPs and Navy auxiliary spare parts. Acting as the Navy's interim depot for this equipment, GEO-CENTERS assembled 20 shipsets of plastic waste processors from the rotatable pool inventory. Through this knowledge we also developed a Technical Repair Standard which will ultimately be used by the Navy depot for this equipment.

#### Solid Waste Pulper Production Support Accomplishments

- November 1997: GEO-CENTERS engineers validate the design drawings to the as-built configurations of large pulper serial numbers 12 through 15 and small pulper serial numbers 10 and 11.
- November 1997: GEO-CENTERS model shop technicians assembled two validation small pulpers and two large pulper units (see Figure 13). The units were packaged for shipment.

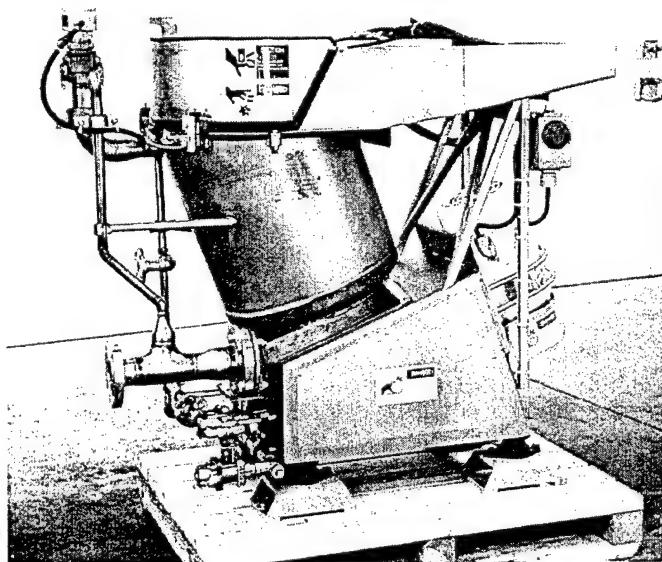


Figure 13. Small Pulper Validation Unit.

- November 1997: Updated the large and small pulper technical manuals specifically adding NSWCCD comments into Chapter 8 "Installation."

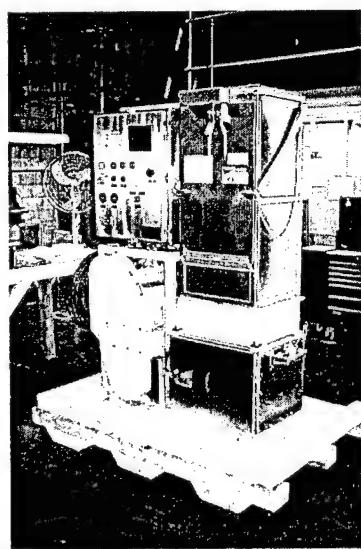
- November 1997: Updated the PLC program for the large and small pulpers in accordance with the final performance criteria.
- November 1997: Attended meetings to resolve manufacturing issues and performed inspections of pulper components at vendor facilities.
- December 1997: Completed final assembly and testing of large pulper LP012 and LP013.
- December 1997: Pulper validation units large pulpers serial numbers 12 through 15 and small pulpers serial numbers 10 and 11 were shipped to Frequency Engineering Laboratories (FEL) and Universal technologies, Inc.
- December 1997: Updated the small pulper installation control drawings (ICD's) to ensure they reflect the latest equipment configuration.
- February 1998: GEO-CENTERS model shop technicians fabricated compressed melt unit motor-brake-gearbox sub-assemblies for DDG 83 through DDG 88 plastics waste processors. (PWPs).
- April 1998: Assisted NAVSEA and NSWCCD with the loadout of the preproduction prototype large pulper and metal glass shredder aboard the USS DECATUR (DDG 73) at Bath Iron Works in Bath, Maine.
- April 1998: Provided engineering, drafting, technical and integrated logistics support to determine the constraints of operating a facility for maintaining and improving the life cycle performance of the PWPs installed in the fleet.
- April 1998: GEO-CENTERS model shop technicians fabricated and delivered one-quarter scale models of a large pulper, compressed melt unit, closed loop cooling unit and their electrical control enclosures, along with display stands to NSWCCD Bethesda.
- May 1998: Incorporated lessons learned during the DDG-73 loadout into the large pulper technical manual and delivered NSWC Philadelphia.
- May 1998: GEO-CENTERS model shop fabricated and shipped a preproduction large pulper and metal/glass shredder to Ingalls shipyard for installation aboard LHD 6.
- July 1998: Assembled, tested and shipped two PWP suites from the existing rotatable pool items from one of the production contractors. We identified quality issues with some of the spare parts and took the appropriate corrective actions (see Figure 14).



**Figure 14. Plastic Waste Processor (PWP).**

- August 1998: GEO-CENTERS was designated by SEA 03L1 as the disposition activity for mandatory return items. Twelve PWP components judged to have high dollar value or deemed highest failure rate items have been designated as mandatory return items on the APL. We will record failure history and trends for development of the sparing philosophy and for potential use in future redesign or equipment modification efforts.
- December 1998: GEO-CENTERS model shop assembled PWP equipment (compress melt units, cooling units and solid waste shredders) from the existing rotatable pool items manufactured by two production contractors. The result of this effort has been a thorough check of the form, fit and function of the contractor supplied spare parts. Parts being reworked or replaced this period include piping assemblies, CMU rams, and pipe clamps.
- September 1999: GEO-CENTERS model shop completed final checkout and testing of four suite Bs (consisting of two Compressed Melt Units, one cooling unit and one shredder each) and delivered them to NSWC Crane.

- January 2000: Received and inventoried the non-NSN auxiliary spares from the NAVSEA warehouses on the east and west coasts. We inspected pulper and shredder parts for conformance with the technical data package.
- January 2000: Continued to upgrade PWP's to current design standards ("A" Condition). A third shipment of Compress Melt Units, Closed Loop Cooling Units and Shredders were upgraded and accepted by the government inspector. We shipped completed units to the Navy's warehouses. We received a fourth shipment for upgrading.
- February 2000: Our engineers attended program reviews at Universal Technologies, Inc. (UTI) and Frequency Engineering Laboratory (FEL) to discuss non-conformances found in a sampling of pulper and shredder auxiliary spares. We then developed plans of action to repair critical defects.
- April 2000: Assembled, tested and shipped six Compress Melt Units, three Closed Loop Cooling Units and one Plastic Waste Shredder to the NAVSEA warehouse at Cheatham Annex.
- April 2000: Received and inventoried additional pulper and shredder auxiliary spares at our warehouse in Carnegie, PA.
- Completed upgrading all production excess PWP equipment to "A" condition. We upgraded 35 Compress Melt Units, 29 Closed Loop Cooling Units and 21 Plastic Shredders. The Navy inspector accepted all units (see Figure 15).



**Figure 15. Plastic Waste Shredder.**

#### 4.1.3 Plasma Arc Waste Destruction System

The U.S. Navy is developing a Plasma Arc Waste Destruction System (PAWDS) to destroy non-hazardous solid wastes aboard ship. This system will be a compact, reliable, safe, and manpower-efficient alternative to the current shipboard suite of solid waste processing equipment. A critical step is rapid gasification of combustible waste matter by plasma heating. The resulting combustible gas mixture rapidly burns in the secondary combustion chamber, minimizing overall system size.

GEO-CENTERS personnel co-invented a plasma-fired eductor for rapid gasification of the waste. We designed and built, at our Engineering Technology Operation's Model Shop in Pittsburgh, PA, a pre-prototype system capable of withstanding the high temperatures (900°C at the eductor wall) expected. This involved use of thermally stable wall materials, water cooling, and critical control of plasma plume alignment.

Our engineers and shop personnel modified a combustion research laboratory at the Naval Research Laboratory to evaluate the pre-prototype eductor system. This test system included feed preparation and injection as an airborne slurry into the eductor. System injectors were designed to direct the feed into the plasma flame to enhance gasification efficiency. The test system also included a secondary combustion chamber and air pollution control sub-system. The entire system was fully instrumented including measurement of flow rates (feed and air), temperatures and pressures at critical system locations. Samples of the gas exiting the eductor and residual ash were obtained during each run to determine the degree of gasification achieved.

The cellulosic test feed was a combination of shredded paper and cardboard. Controlled test variables included:

- Eductor geometry
- Feed size
- Feed flow rate
- Air flow rate
- Plasma power
- Eductor temperature

Early test results indicated a bimodal distribution of feed within the eductor. Some of the feed was burned completely, generating carbon dioxide, while most of the feed was not gasified. These results agreed with subsequent computational fluid dynamics model predictions that much of the feed hugged the eductor wall and did not contact intimately the eductor flame. A collar

around the plasma torch head to direct the feed into the plasma flame resolved this problem. This change resulted in a significant improvement in gasification rates.

Results of importance to the design and operation of a full-scale prototype system, the next step in the development of PAWDS for U.S. Navy ships, achieved under this project included:

- Effective feed impingement into the plasma flame is critical to efficient gasification
- The use of a collar around the plasma torch head to directing feed into the plasma flame improved gasification efficiency
- Narrow throat eductor designs improved gasification efficiency
- Increasing eductor temperature to the 900°C level is critical to efficient gasification
- Gasification of an average of 70% of the cellulosic feed can be achieved reliably
- The gases exiting the eductor burn rapidly in the secondary combustion chamber
- The combination of gasification in the eductor and burning in the secondary combustion chamber readily achieves the International Maritime Organization goal of 90% destruction of the incoming waste
- Increasing air flow increases oxygen concentration in the eductor but decreases residence time producing a mixed effect on gasification rates

The results of the pre-prototype PAWDS project were regularly presented to U.S. Navy personnel at a series of Bi-Weekly meetings to facilitate technology transfer to the development and design of the prototype PAWDS test system. GEO-CENTERS engineers contributed directly to the design of the full-scale prototype system as part of this project.

#### Plasma Arc Waste Destruction System (PAWDS) Accomplishments

- April 1998: Prepared a briefing for presentation at the May 1998 Advanced Incinerator Specification working group meeting reviewing the current MIL STD Vent-O-Matic Incinerator design.
- April 1998: Prepared a baseline heat and mass balance for processing concentrated Naval Liquid Waste for a 6000 man conventional carrier using a vortex incinerator configuration. NAVSEA requested that the information be presented at the May 1998 Advanced Incinerator Specification meeting.
- April 1998: Met with NAVSEA 03R16 to discuss the potential use of steam reforming for integrated treatment of graywater, sewage and waste oil.

- May 1998: Supported NSWCCD in development of performance specification for advanced shipboard incineration. Activities included the design of a generic incineration system.
- June 1998: Supported development of a test plan for evaluating the Golar 500 incinerator system for test installation on CVN-73.
- July 1998: Assisted NSWCCD in preparations of a performance specification for Advanced Shipboard Incinerator System.
- July 1998: Assisted NSWCCD in preparation for a Plasma Arc Advanced Technology Demonstration.
- December 1998: Reviewed critical documents and major reports at the request of the PAWDS ATD PM (NSWCCD 63).
- December 1998: GEO-CENTERS engineers attended a meeting to review and revise objectives and experimental requirements for the cold flow eductor testing facility at NSWCCD, and follow-on work at the NRL thermal plasma system eductor installation.
- December 1998: Prepared a list of candidate contractors capable of responding to the RFP when the replacement incinerator specification package is released.
- March 1999: Attended the Society of Automotive Engineers (SAE) 1999 International Congress and Exposition and gave an informal presentation on this meeting to the NSWCCD Fluid and Chemical Branch.
- April 1999: Member of the Program Advisory Committee and co-chair (with Dr. Soto of ONR) of the Hydrothermal Oxidation session, reviewed papers submitted for the 1999 International Conference on Incineration and Thermal Treatment Technologies.
- May 1999: Attended the 1999 International Conference on Incineration and Thermal Treatment Technologies. Dr. Peterson presented two papers (one co-authored with D. Counts et al and the other co-authored with Dr. B. Sartwell of NRL, et al) at the conference.
- September 1999: Attended PAWDS bi-weekly meetings to report on the status of the Test Integrated Product Team (IPT) and the pre-prototype eductor tests. Led the test IPT in continued development of the Plan of Action and Milestones (POA&M) for projected tests at NRL.
- September 1999: Led a meeting of PAWDS Computational Fluid Dynamics (CFD) sub IPT members to discuss NRL experimental plans.
- September 1999: GEO-CENTERS engineers supported the PAWDS eductor testing at NRL. (see Figure 16). We increased delivered plasma power, uncovered and corrected problems

with mechanical and electrical components, and evaluated chemical reactions occurring in and downstream of the plasma eductor. We diagnosed and corrected several power supply problems, increasing power to the eductor. We determined that the exhaust stack and secondary combustion chamber air flow sensors were saturating.

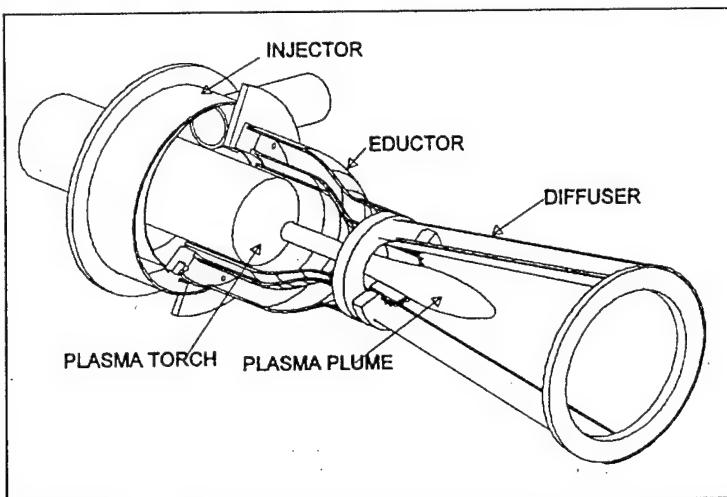


Figure 16. PAWDS Eductor Assembly.

- October 1999: R. Richard, GEO-CENTERS engineers and scientists drafted the PAWDS Experimental Eductor Test Report.
- November 1999: Developed two modified eductor designs to increase turbulence in the prototype PAWDS eductor. GEO-CENTERS shop fabricated the new eductors.
- November 1999: R. Richard upgraded the PAWDS eductor data acquisition system to accurately monitor observed system oscillations in flow rates and pressures.
- December 1999: T. Harasti developed software to improve the analysis and presentation of test data integrating thermal, gasification, and gas analysis data to improve system performance analysis.
- January 2000: GEO-CENTERS fabricated two narrow throat eductor liners, installed one in the pre-prototype system, and performed tests at varying feed rates, air flow rates and wall temperatures.
- March 2000: GEO-CENTERS shop personnel replaced eductor liners with TBC liner.

## 4.2 SHIPBOARD LIQUID WASTE CONCENTRATION AND DISPOSAL

### 4.2.1 Oily Waste Concentration and Compensated Fuel Ballast Tank Model

The principal source of oily wastewater on Navy ships is bilgewater. Bilgewater generation and oil content is influenced by many factors including ship class, equipment operating condition, equipment casualties, maintenance, etc.. Bilgewater generation surveys have found that rates can vary from as little as 100 gallons per day to more than 50,000 gallons per day and the oil content can range from as little as 10 parts per million (PPM) to twenty or more percent. Currently, Navy regulations restrict the discharge of processed bilgewater to oil contents less than 15 PPM, which is generally accepted as the level at which oil will form a sheen on water.

Several oil/water separator (OWS) systems have been developed and installed in the fleet to process bilgewater. The 10-gallon-per-minute 10-NP OWS is installed on most small combatants and auxiliaries and the 50-gallon-per-minute C-50 is installed on the larger amphibious ships and aircraft carriers. Both systems work well with non-emulsified oil, and work in conjunction with an oil content monitor (OCM) which evaluates the quantity of oil in the effluent. In operation, effluent with oil concentration greater than 15 PPM is recirculated back to the oil waste holding tank, while effluent with oil concentrations less than 15 PPM is discharged overboard. However, neither of the separators currently in use can effectively remove emulsified oil from the bilge water waste streams.

GEO-CENTERS engineers, working with engineers at NSWCCD Carderock laboratory, have been investigating ultrafiltration membranes to remove emulsified oil from bilgewater. Our tasking has been to conduct detail design, fabrication and checkout testing of prototype ultrafiltration membrane systems. Two 10-gallon-per-minute, one 50-gallon-per-minute and one "combined" system were designed and fabricated. The 10-gallon-per-minute and 50-gallon-per-minute system were designed as add-on systems, that is, these prototype systems work in conjunction with the current 10-NP or C-50 system to reduce the oil content, specifically in the emulsified portion of the effluent, to less than 15 parts per million. The "combined system" incorporates the function of the 10-NP and the ultrafiltration membrane treatment unit into one integrated system, and would be a replacement for the current oil pollution abatement system. The ceramic membranes have a pore size of fifty angstroms. No particle longer than this can pass through them which effectively filters out oil and other contaminates even in an emulsified state. Shipboard testing of the 10-gallon-per-minute prototype consistently average less than 10-parts-per-million oil in the effluent regardless of influent oil concentrations. Oil content monitors work well in a laboratory setting but in the relatively harsh ship environment their accuracy becomes questionable. The use of an ultrafiltration system downstream of an oil water separator may preclude the need for an oil content monitor. Membrane pore size will make it physically impossible for oil to be discharged in concentrations exceeding 15 parts per million.

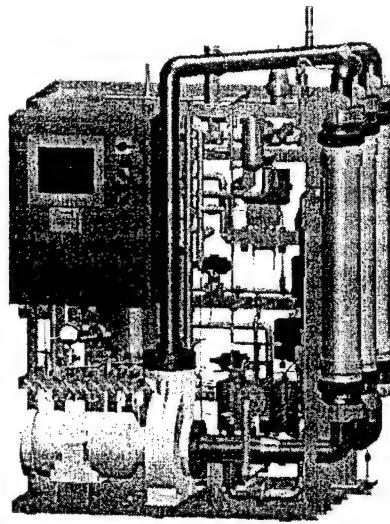
Another problem associated with oily wastewater is the water discharged during refueling of ships with compensated fuel ballast tank systems. Ships with compensated fuel ballast tank systems use several partitioned fuel tanks that contain both water and fuel to correctly ballast the

ship. As fuel is consumed, seawater is added to the tanks to keep the ship within specified stability parameters. The issue with these systems is that a portion of the water, particularly at the interface between the fuel and seawater, becomes contaminated with fuel. When the ship is refueled, some water contaminated with fuel is displaced overboard. No existing separator can process this waste stream because the refueling occurs at such a high rate. Therefore, the Navy is investigating physical modifications to the structural elements of the tanks to minimize fuel/water mixing. GEO-CENTERS' role in this program has been the construction and modification of a one-fourth-scale plexiglass model of one of the compensated fuel ballast tanks on a DDG 51 class ship. Our engineers have also participated in the development of the data collection system associated with the plexiglass model and the development of a unique level probe that can accurately record the position of the water/oil interface as the model is drained and filled. GEO-CENTERS' engineers and statisticians have also participated in the testing, data collection and subsequent analysis of the data associated with the compensated ballast tank model.

#### Oily Waste Concentration and Compensated Fuel Ballast Tank Model Accomplishments

- November 1997: GEO-CENTERS developed a performance curve of breakthrough time versus influent oil in water concentration for a selected sorbent (adsorption material) for use in small craft OWS polishing system.
- November 1997: Discussed Computational Fluid Dynamics (CFD) work scope with representatives of West Virginia University to analyze two-fluid entrainment inside compensated ballast system tanks.
- December 1997: Initiated procurement of material to build a small Plexiglas model of the DDG 51 fuel tanks in support of the compensated ballast program.
- December 1997: Attended a DDG 12 integrated oily waste treatment system planning meeting at NSWCCD Bethesda.
- December 1997: Hosted a liquid waste program review meeting for SEA 03R16 at GEO-CENTERS INC. offices in West Mifflin, PA.
- December 1997: Continued with Level III design of the oily waste ultrafiltration system Engineering Development Model (EDM). We developed the general arrangement of the system using 3 dimensional solid modeling. We have started a value engineering study, focusing on cost reduction based on component need and selection, and fabrication techniques.
- December 1997: Developed and submitted a preliminary survey plan to determine bilge water generation rate (BGR) and OWS effluent characteristics for MHC 51, MCM 1, and PC 1 class ships.

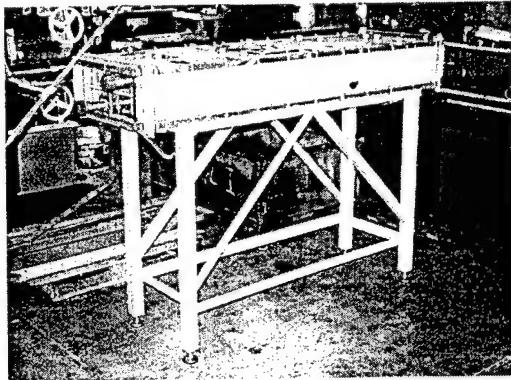
- January 1998: Contracted with West Virginia University to perform CFD analysis for compensated ballast program.
- January 1998: Completed a value analysis of electrical components on the oily waste ultrafiltration system EDM resulting in a potential savings of \$8000.00 per unit.
- April 1998: Delivered a self-contained, automated, working demonstration of an ultrafiltration membrane system to NSWCCD (see Figure 17).



**Figure 17. 10 GPM Oily Waste Ultrafiltration System Solid Model.**

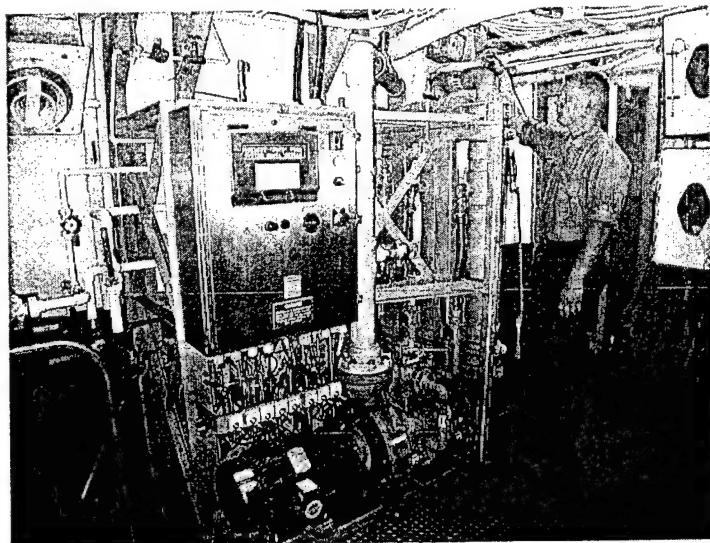
- April 1998: Completed ship checks to determine space availability on USS DWIGHT D. EISENHOWER (CVN 69), USS BATAAN (LHD 5), and USS SAIPAN (LHA 2), in support of the 50 GPM Ultrafiltration Membrane System program.
- May 1998: Prepared a Process and Instrumentation Diagram (P&ID) for the Combined Oil/Water Separation System depicting the system as divided into three separate modules (feed, membrane and bulk oil separator). This modularization will allow design and fabrication of parts for the system to be concurrent with the bulk oil separator selection process.
- June 1998: Prepared a CAD model of a Laboratory Combined Oil/Water Separation System.
- June 1998: Developed a thermal/hydraulic simulation model for the Laboratory Combined System using SIMSMART software. This model will be used to evaluate system performance and predict the effect of changes.

- June 1998: Completed fabrication of the compensated ballast tank Plexiglas model and support stand (see Figure 18).
- July 1998: Delivered the compensated ballast tank model stress and deflection analysis to NSWCCD. This analysis was validated with empirical data derived from hydro testing at the GEO-CENTERS model shop.
- July 1998: Fabrication, in-shop testing and check out of the 10 GPM oily waste EDM unit 1 was completed and the unit was delivered to NSWCCD. We provided assistance in the start up effort at the lab including minor modifications to the PLC program.



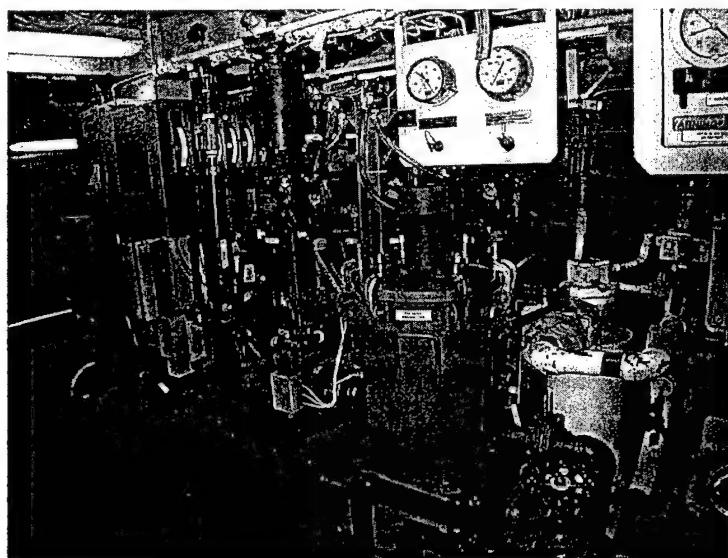
**Figure 18. Compensated Ballast Tank Plexiglas Test Model.**

- July 1998: Provided technical support to the Alteration Installation Team (AIT) regarding EDM Unit 2 external interface concerns. The AIT in San Diego to prepare the Unit 2 space aboard USS RUSHMORE (LSD 47) (see Figure 19).



**Figure 19. 10 GPM Oily Waste Ultrafiltration Unit onboard USS RUSHMORE.**

- July 1998: Completed a draft report regarding unsatisfactory results from a membrane integrity test performed by Ingalls shipyard during installation of an oily waste polishing system on the USS McFAUL (DDG 74).
- August 1998: Delivered one set of spare internal panels for the compensated ballast tank model to NSWCCD. These panels are used to modify the tank models mixing characteristics when investigating sea water hideout.
- August 1998: Fabrication, in-shop testing and check out of the 10 GPM oily waste EDM unit 2 was completed and the unit was delivered to Naval Base San Diego (see Figure 20). Drawings depicting the as-built configuration of EDM Unit 1 and EDM Unit 2 were delivered to NSWCCD.

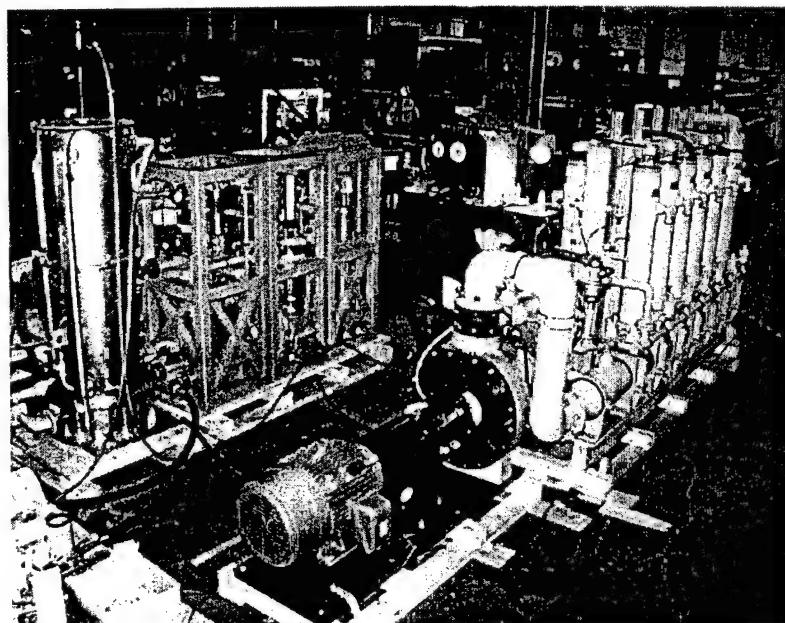


**Figure 20. Shipboard Combined OWS System.**

- August 1998: Delivered the preliminary logistics package for the Oily Waste EDM including the Tech Manual, EOSS, APL, PMS and installation guide to NSWCCD Code 633.
- August 1998: Participated in a level I design review for the 50 GPM Ultrafiltration Membrane System held at GEO-CENTERS Crystal City offices. The overall design and configurations were approved with no major changes.
- September 1998: GEO-CENTERS received the oily waste EDM unit 1 back from the lab where we prepared it for shock, vibration and EMI testing.
- October 1998: Completed work on the preliminary layout of the Shipboard Combined System and the layout of the 10 GPM oily waste ultrafiltration unit and associated equipment.

- November 1998: Developed and submitted to NSWCCD test plans for EMI, vibration and shock tests for the EDM 1 unit. GEO-CENTERS shop cleaned, flushed, and transported the unit to Noise Unlimited for performance of the tests.
- December 1998: Completed an industry survey of alternative suppliers of ceramic and polymeric membranes for use in oily waste treatment systems.
- January 1999: Conducted a debriefing of NSWCCD Code 633 and NAVSEA 03R on the results of the EMI and Vibration Tests of the 10 gpm Oily Waste EDM that were performed in December 1998.
- January 1999: Prepared fabrication drawings for the Combined System feed control test loop.
- February 1999: Initiated development of system layouts for oily waste EDM 2 that would incorporate modular design techniques to facilitate interchange of several different membrane designs.
- February 1999: Prepared a test plan to evaluate the effects of the soft starter upon the reliability of ceramic membranes for oily waste EDM 2.
- March 1999: Completed analysis and investigation of the 10 gpm EDM vibration test failure. GEO-CENTERS shop will implement structural modifications to the unit.
- May 1999: B. Owsenek collaborated with NSWCCD personnel to prepare a test plan for the laboratory analysis of ultrafiltration (UF) membranes selected for evaluation. We also reviewed the U. S. Filter UF membrane laboratory test plan.
- June 1999: Continued disassembly and modification of the 10 gpm ultrafiltration EDM returned from the USS RUSHMORE (LSD 47).
- July 1999: Completed modifications of the 10 gpm ultrafiltration EDM returned from the USS RUSHMORE (LSD 47) and shipped it to Noise Unlimited Laboratories for shock and vibration testing. Vibration testing in accordance with MIL-STD-167-1 was successfully completed on 24 July, Shock testing in accordance with MIL-S-901D (NAVY) was successfully completed on 27 July.
- July 1999: Attended the Combined OWS/Ultrafiltration Membrane System Program Review on 16 July.
- July 1999: Delivered two radio frequency capacitance probes, a transmitter and a receiver to NSWCCD Code 633 for the 1/8 scale compensated ballast tests.

- August 1999: Developed, tested and shipped to NSWCCD an oily waste feed system test loop to evaluate positive displacement pumps and self regulating control valves for the combined OWS system.
- September 1999: Performed a membrane integrity test on the 10 gpm EDM to determine if earlier shock and vibration tests damaged the membranes. The test revealed that one or more of the membranes had failed. All were inspected and results documented.
- September 1999: Prepared 50 gpm Ultrafiltration Membrane System interface drawings for use by the Alteration Installation Team.
- October 1999: GEO-CENTERS shop began fabrication of the 50 GPM Ultrafiltration System feed tank. We developed electrical and instrumentation drawings and continued work on the PLC and display unit programs.
- December 1999: R. Anderson, completed membrane integrity testing of the ceramic and silicon carbide membranes with the G-11 epoxy coated seals and documented the procedure for future assemblies.
- December 1999: Performed final assembly and hook-up of the 50 GPM Ultrafiltration System auxiliary piping module, membrane assembly, feed tank module and recirculation pump (see Figure 21). We prepared test procedures for operational and membrane integrity testing.



**Figure 21. 50 GPM Ultrafiltration Membrane System.**

#### 4.2.2 Graywater Concentration

U.S. Navy ships are required to hold blackwater in regulated areas and within three miles of the coast. In contrast, graywater discharge is currently not regulated, but more stringent environmental regulations are anticipated and current practice on many ships is to avoid the overboard discharge of graywater within three miles of port and to discharge to land-based facilities while in port. Also, the cost of discharging blackwater and graywater while in port is expensive and costs are increasing worldwide.

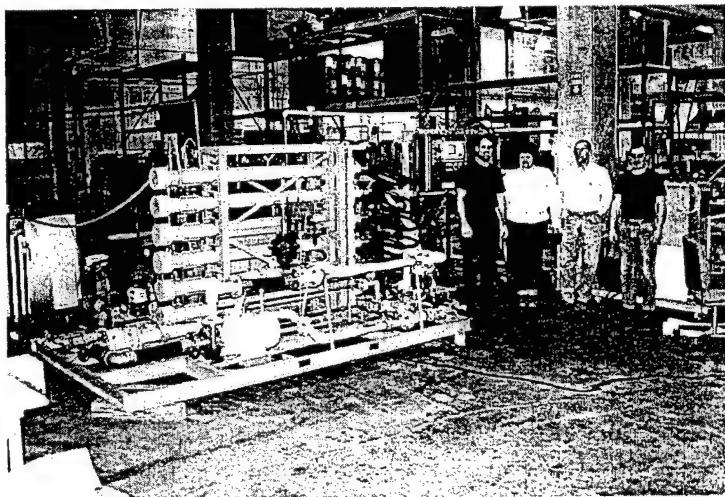
Under the sponsorship of the Naval Sea Systems Command and working with engineers at the Carderock Division of the Naval Surface Warfare Center (NSWCCD), GEO-CENTERS engineers and technicians are working to develop technologies appropriate for the treatment and concentration of graywater and blackwater.

A typical land-based biological wastewater treatment system requires large aeration tanks with settling and clarification chambers and long retention times to remove suspended solids and oxidize dissolved organic material. These systems require considerable operator attention for sludge removal and chemical addition and, as stated previously, are space intensive. For these reasons, conventional biological systems are not particularly well suited for shipboard applications where space and manpower are limited. The challenge is to develop a treatment system that meets Navy shipboard requirements for affordability, compactness, low operation and maintenance times, high reliability and safety as well as satisfying Navy shock, vibration and EMI criteria. Membrane ultrafiltration systems incorporating aerobic biological pretreatment and ultraviolet light post treatment disinfection were chosen for development by the engineering team. Membranes effectively reject a high percentage of suspended solids and bacteria, and aeration stimulates microbial activity that consume the majority of the soluble organic content of the wastewater. The effort under this tasking was to design, build, and operate laboratory systems that would demonstrate effective operations with short residence times. Systems that can operate with residence times less than 10 hours offer significant potential for shipboard graywater and blackwater treatment applications.

Tasks accomplished include the design and fabrication of a laboratory engineering development model number 1 (EDM-1), which is a 75-person graywater tubular membrane treatment unit. GEO-CENTERS also assisted with installation and start-up testing of EDM-1, fabricated an enhanced membrane laboratory test rig, and completed a report on the effects of enhanced aeration for bioreactors. We also designed a shipboard version of the tubular membrane system designated as EDM-2. Although EDM-2 was never built because of advances in the "in-tank" membrane system, the control system was fabricated for use with the laboratory upgraded baseline (UBS) tubular membrane system. GEO-CENTERS also designed, fabricated and assisted with installation of a "low-height" bioreactor for laboratory tests with the UBS system. This system was also used to implement and demonstrate ethernet data logging in the laboratory. We also investigated and selected alternative message displays for graywater controllers, supported laboratory testing of the UBS system and started the development of advanced in-tank membrane treatment systems.

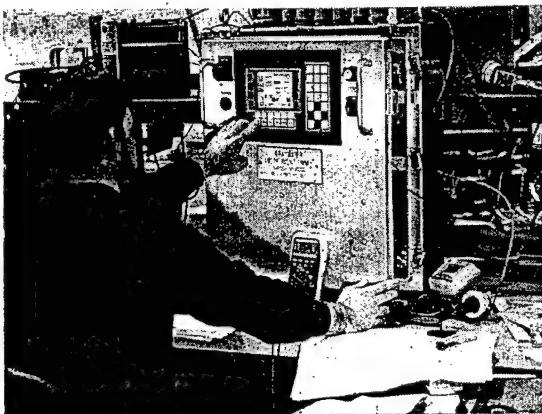
**Graywater Concentration Accomplishments**

- November 1997: Completed an industry and literature search to determine if any vendors offer a packaged system designed for waste water treatment (aeration) using membranes and to locate vendors of other system components, such as diffusers and injectors.
- December 1997: Attended a graywater EDM-1 controls design review meeting at NSWCCD Bethesda.
- December 1997: Delivered to NSWCCD Bethesda, an interim report on products suitable for enhanced aeration, including findings and a basic test outline.
- January 1998: Completed system and operation testing of the graywater EDM 1 unit and shipped it from GEO-CENTERS model shop to NSWCCD Bethesda (see Figure 22). Work continued on a safety (hazard) analysis and on the operation manual. We also delivered a final copy of the failure modes and effects criticality analysis to NSWCCD.



**Figure 22. Graywater Tubular Membrane Treatment Unit (EDM 1).**

- January 1998: Visited NSWCCD Bethesda to assist with installation of EDM 1 and review equipment operation (see Figure 23).
- January 1998: Placed purchase orders for four membrane modules suitable for enhanced aeration to be used in testing.
- February 1998: Completed programmable logic controller and message display unit software for the full scale, 75 person, Graywater Tubular Membrane Treatment Unit.



**Figure 23. Graywater Control Panel.**

- February 1998: Wrote and submitted to NSWCCD Bethesda, a report on the calibration of EDM 1 instruments (Pressure transmitters, temperature transmitters, and flow meter).
- April 1998: Completed the preliminary Safety Hazard analysis for the Non-Oily Wastewater, Full-scale, 75-person, Graywater Tubular Membrane Treatment Unit EDM 1 and delivered it to NSWCCD.
- April 1998: Completed work on a laboratory membrane-testing rig for enhanced aeration of graywater.
- May 1998: GEO-CENTERS engineers made programming changes to EDM 1 throughout the month of May to support laboratory testing of the unit.
- May 1998: Completed fabrication and delivered a control enclosure identical to the EDM 1 for use with SIMSMART modeling.
- June 1998: Reviewed test plan and placed a purchase order with XenoTechnics for flow rate and Non-Oily Wastewater Sample Analysis data gathering via ship checks of USS VELLA GULF and USS LEYTE GULF collection, holding and transfer systems.
- July 1998: Supported laboratory testing by diagnosing problems with the baseline treatment system and the liquid waste transfer system.
- July 1998: Met with laboratory personnel and selected a replacement foam abatement nozzle for evaluation in the EDM-1 bioreactor. Placed a purchase order for the nozzle.
- August 1998: Developed several different versions of a system performance specification for the liquid waste transfer system.

- August 1998: Attended the August 1998 graywater program review with NAVSEA 03R and NSWCCD.
- September 1998: Redesigned, fabricated, installed, and tuned a new laboratory Liquid Waste Feed System controller.
- September 1998: Prepared a preliminary process and instrumentation diagram (P&ID) and a list of components for EDM-2 graywater treatment system (see Figure 24).
- October 1998: Completed design of a 4.3 Kw in-line process heater for the half scale treatment system.

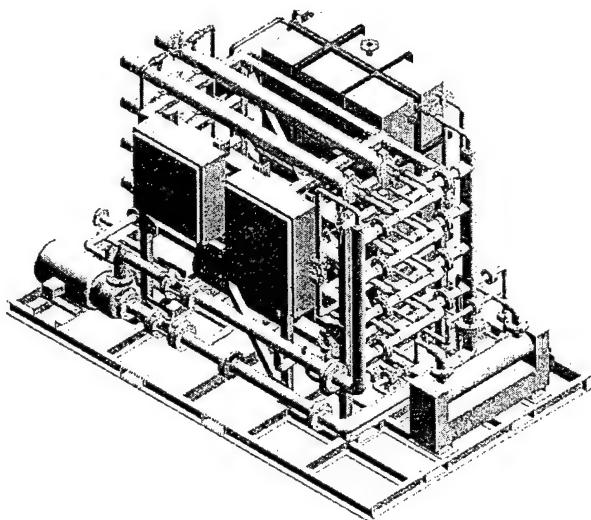
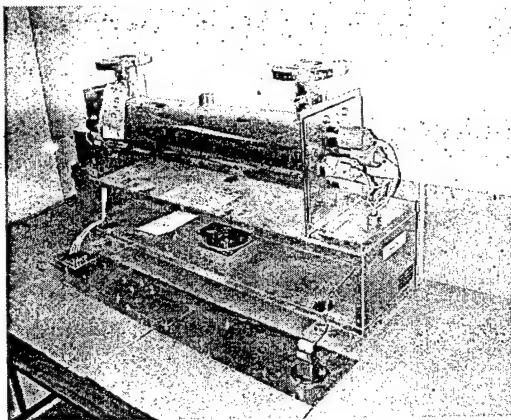


Figure 24. Graywater Engineering Design Model (EDM 2).

- October 1998: Prepared layout drawings for the EDM-2 treatment system and transmitted copies to NSWCCD for review.
- November 1998: Completed fabrication and testing of a 4.3 Kw in-line process heater for the upgraded baseline system.
- November 1998: Presented to NSWCCD PLC CPU and ethernet data logging options for EDM-2 and the half scale treatment system.
- December 1998: Submitted program specification for the new EDM-1 flush and permeate discharge operation to NSWCCD.
- December 1998: Completed design and detail drawings for the EDM-2 and upgraded baseline system bioreactor. Submitted drawings to NSWCCD for review.

- March 1999: Completed installation of a DC controller and an algorithm to incorporate a variable speed concentrate pump to the EDM-1 system.
- April 1999: Provided support for laboratory testing of the EDM-1 and Upgraded Baseline System (UBS) at NSWCCD.
- April 1999: Purchased a variable frequency drive for the aeration blowers to be used in lab testing of the small bioreactor.
- June 1999: Completed and delivered the small bioreactor tank and associated components to NSWCCD. Delivered P&ID diagrams and electrical drawings to NSWCCD.
- June 1999: Assisted with installation of the small bioreactor in the laboratory UBS system.
- June 1999: Installed an ethernet connection from the EDM-1 PLC to a personal computer to facilitate data logging.
- July 1999: Completed work on EDM-2 detailed design drawings and delivered the design report to NSWCCD.
- August 1999: Completed fabrication of the EDM-2 electrical enclosures.
- August 1999: Completed preliminary process and piping and instrumentation diagrams for a proposed laboratory graywater test system.
- September 1999: Completed the UBS program checkout and turned operation of the system over to NSWCCD personnel.
- November 1999: Recommended modifications to two commercial ultraviolet (UV) treatment units to improve their shock and vibration resistance. Following approval by NSWCCD our shop completed the modifications and shipped the units to Noise Unlimited Laboratories for testing (see Figure 25). GEO-CENTERS engineers witnessed the tests with NSWCCD personnel.
- December 1999: Submitted a final report on shock and vibration testing and analysis of the Ultraviolet Water Treatment units.
- December 1999: Updated the process diagram and Piping and Instrumentation diagrams (P&ID's) for the proposed laboratory test system.



**Figure 25. Commercial UV Treatment Unit.**

#### 4.2.3 Vortex Incinerator

National and international regulations currently restrict the overboard discharge of ship-generated liquid waste. Furthermore, it is anticipated, that during the twenty-first century, discharges of untreated sewage, graywater, and oily wastes will be further restricted in many littoral areas throughout the world. Future combatants will operate primarily in these littoral areas. As a result, NAVSEA initiated a research and development program to provide future Navy surface combatants with the capability to completely destroy liquid wastes aboard ship, maximizing shore independence, and minimizing waste off-load costs in foreign and domestic ports. Under this program, engineers at the Carderock Division of the Naval Surface Warfare Center and GEO-CENTERS have developed a liquid waste abatement strategy called the integrated liquid destruction system (ILDS).

The ILDS contains three distinct elements, two of which were discussed earlier in this summary report: non-oily liquid waste treatment, oily waste treatment, and thermal destruction. The focus of the ILDS is to minimize each of the waste streams so that a shipboard thermal destruction system can be used to process the remaining volume of waste. One device chosen as the potential solution to thermal destruction of liquid waste is the advanced vortex incinerator.

One class of Navy ships, the Spruance class, is currently equipped with vortex incinerators for destroying sewage. These ships use a vacuum collected sewage system, which greatly reduces the total volume of sewage by reducing the amount of fresh water used for flushing, and two vortex incinerators which provide the option of burning the sewage collected in lieu of discharging it overboard or to a pier connection when in port. These incinerators use auxiliary fuel or marine diesel fuel and are rated at 0.5 gallons per minute throughput. Atomized fuel and high-velocity combustion air are mixed in a recirculation chamber designed to draw hot gases from the combustion chamber and superheat the mixture to the ignition temperature. Rising overseas sewage disposal costs have resulted in increased use of the vortex incinerators, and part of the effort of this task has been directed towards enhancing the operation of the current sewage

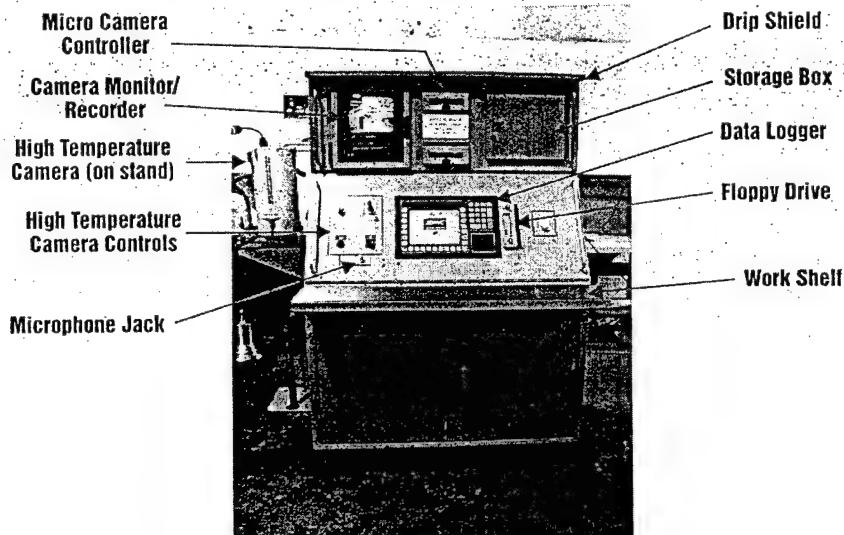
disposal system. Upgrades were installed and tested on two ships: USS THORN (DD 988) and USS BRISCOE (DD 977) with excellent results.

GEO-CENTERS participation in this task was focused in two main areas: demonstration of the vortex incinerator as a viable shipboard technology, and modification of a DD 963 class vortex incinerator to destroy concentrated liquid waste in the laboratory.

To demonstrate the shipboard viability of the vortex incinerator, GEO-CENTERS engineers and technicians conducted a thorough review of the existing shipboard incinerator and the issues associated with its performance. As a result of this review, we designed, fabricated and installed new incinerator liners, intermediate shells, main access and ash doors and seals, upgraded the electrical control panels, fabricated and installed a replacement choke valve controller, as well as upgraded and overhauled other selected components. In addition, the technical manuals, maintenance requirements cards, parts lists and other logistics documents were updated to reflect the latest configuration. In support of the second objective GEO-CENTERS engineers and technicians supported the start-up and fine tuning of the engineering development model (EDM) at the Carderock laboratory. This EDM was designed and built by our model shop on an earlier contract. Our work scope included development of test plans for burning oily waste, graywater and blackwater in various combinations, as well as hands-on support during testing and analysis of the collected data.

#### Vortex Incinerator Accomplishments

- October 1997: Assisted NSWCCD onboard the USS BRISCOE (DD 977) to replace the incinerator's immediate shell.
- November 1997: Visited USS THORN (DD 988) to examine their marine sanitation device (MSD) system to determine a typical shipboard configuration on which to base a technical manual being developed for the MSD system.
- December 1997: Participated in a MSD technical review meeting at NSWCCD Annapolis, MD.
- January 1998: Assisted NSWCCD Bethesda on board the USS THORN (DD 988) in examining the fresh water feed system and the vacuum collection tank (VCT) transfer pump.
- February 1998: Assisted NSWCCD Bethesda on board USS THORN (DD 988) with overhaul of selected components of the vacuum collection tank and incinerator system (see Figure 26).
- April 1998: Successfully completed modifications to the fresh water flush system and the marine sanitation system aboard USS THORN.

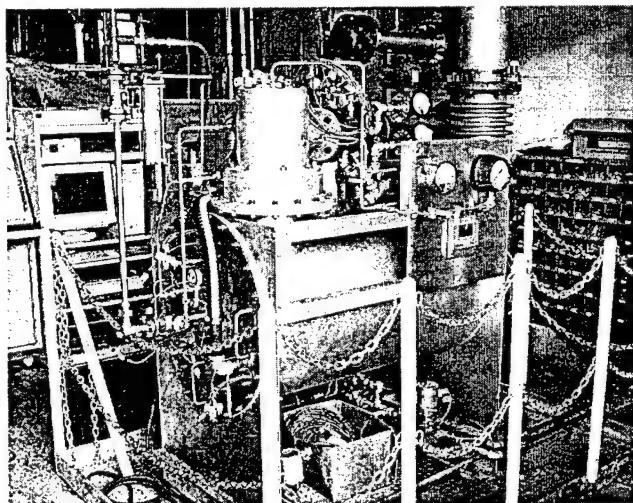


Data Collection System Instrument Console

Figure 26. Data Collection System Instrument Console.

- April 1998: Supported start-up of the EDM incinerator at NSWC laboratory at Carderock.
- May 1998: Presented the "Data Collection System for Navy Incinerator Engineering Development Model" during the poster session of the incinerator conference that was held at Salt Lake City, Utah.
- June 1998: Supported NSWCCD at the lab by checking out the datalogger and incinerator instrumentation. Problems with 6 thermocouples, one JP-5 flowmeter and the datalogger were encountered and replacement parts were installed.
- July 1998: Supported NSWCCD in the start-up and fine tuning of the Engineering Development Model incinerator.
- July 1998: Assisted NSWCCD in the installation of developmental equipment associated with the Marine Sanitation Device on board USS Thorn.
- August 1998: Per direction of NSWCCD, investigated an alternative gasket material for use on the access and ash doors of the incinerator.
- October 1998: Visited NSWCCD lab to install repaired output cards for secondary air, door cooling, low pressure and combustion air.

- October 1998: Visited the lab to reprogram the datalogger time record interval and to witness a test burn and to verify that all instrumentation was working properly.
- December 1998: Reinstalled the repaired laboratory EDM incinerator inner liner and replaced pressure transducers at NSWCCD.
- December 1998: Provided rolled Haynes Alloy 160 plates to repair a damaged inner liner onboard USS THORN.
- January 1999: Modified an existing incinerator access door.
- February 1999: Developed design drawings for the lab incinerator improvements (see Figure 27).
- February 1999: Developed fabrication drawings for replacement copper access door and ash door gaskets to be installed on USS THORN.
- March 1999: Completed drawings of the incinerator temperature probe for the lab EDM upgrade.
- March 1999: Completed a vendor evaluation and comparison between Honeywell and Fireye for the incinerator PLC "burn manager".



**Figure 27. EDM Incinerator at NSWCCD.**

- April 1999: Replaced a damaged thermocouple on the lab vortex incinerator EDM and performed a minor weld repair on the lab EDM inner liner and access door.

- April 1999: Provided one set of EDM incinerator copper gaskets and one set of soft (Lytherm) gaskets to NSWCCD for use in lab burn tests.
- April 1999: Purchased Cimplicity software for the incinerator PLC controller.
- May 1999: Submitted for final review Technical Manual Chapters 1, 2 and 3, and the Maintenance Requirement Cards (MRC) for the Integrated Logistics System (ILS) on USS THORN.
- May 1999: Developed an algorithm to compare carbon monoxide and oxygen concentration measurements with International Maritime Organization standards. The algorithm was incorporated into NSWCCD's ACCESS program.
- May 1999: Supported NSWCCD in start-up of the Lab EDM incinerator by providing a list of operating ranges for incinerator temperature, flows and pressures.
- May 1999: Successfully tested the Lab EDM incinerator choke valve interface wiring using a mock-up to simulate operating conditions.
- May 1999: Purchased hardware to measure the Lab EDM incinerator internal temperature profile. The resulting data was used to design the internal combustion chamber thermocouple.
- May 1999: Purchased a multi-level Inconel 625 thermocouple probe to replace Hastalloy probes that were corroding in service.
- June 1999: Model Shop developed a detail design drawing for the NSWCCD modified ash door concept and fabricated a modified ash door.
- June 1999: Ordered an air snubber to smooth the differential pressure gauge fluctuations and an air dehumidification filter for the EDM incinerator.
- June 1999: Completed fabrication of the incinerator EDM Programmable Logic Controller (PLC).
- July 1999: Successfully installed an upgraded choke valve and controller on the Lab EDM vortex incinerator. We demonstrated the choke valve adjustment procedure for NSWCCD technicians and videotaped the procedure for future training.
- July 1999: Fabricated and installed a modified ash door onto the incinerator access door.
- July 1999: Supported the 30 gallon per hour laboratory test burns of blackwater, graywater and oily water. We developed a test plan for burning graywater with decreasing amounts of solids to determine if a relationship exists between graywater solids loading and carbon monoxide concentration.

- August 1999: Supported NSWCCD by increasing the capacity of the Lab vortex incinerator from 35 gph to 45 gph.
- August 1999: Shop installed a modified ash door on the lab EDM.
- September 1999: Fabricated and installed a replacement choke valve controller on the Lab EDM at NSWCCD.
- September 1999: Designed and prepared drawings for a combustion chamber thermocouple. Ordered a new multi-level thermocouple probe fabricated from Haynes Alloy 230.
- September 1999: Completed and delivered for review the Marine Sanitation Device Technical Manual for USS THORN (DD 988).
- September 1999: Met with Mr. J. Billhime, NSWCCD-SSES APL analyst, to provide technical guidance and background for APL decisions. We provided revised Maintenance Requirement Cards (MRC) to NSWCCD-SSES personnel for implementation.
- October 1999: Participated in the Liquid Waste Thermal Destruction meeting at Carderock on Nov. 25. This meeting reviewed the status of lab testing and CFD modeling.
- November 1999: C. Jordan completed and delivered to NSWCCD final drawings for fabrication of the modified vortex incinerator access doors for USS THORN (DD 988).
- November 1999: Prepared a drawing for machining spray-formed liners for the vortex incinerator. We provided the drawing and quotes for performing the machining to NSWCCD.
- December 1999: Installed the internal combustion chamber thermocouple and digital readout for the modified choke valve on the NSWCCD test system.
- December 1999: Supported the installation of a digital display flowmeter aboard USS THORN (DD 988). We provided electrical drawings showing the 100 VAC source powering the flowmeter.

## 5.0 ENVIRONMENTAL PROGRAM SUPPORT

The GEO-CENTERS Crystal City Office performed work under this contract in two primary program areas: ozone-depleting substances (ODS) and the Navy's shipboard environmental information clearinghouse (SEIC); and environmentally sound ships for the 21<sup>st</sup> century (ESS-21).

## 5.1 OZONE-DEPLETING SUBSTANCES AND SHIPBOARD ENVIRONMENTAL INFORMATION CLEARINGHOUSE

The primary thrust of the ODS/SEIC effort was to develop and make available to other Navy activities a comprehensive database on shipboard environmental protection systems and alternative chemicals and processes for replacing current uses of ODS within the Navy. GEO-CENTERS provided technical backup and assisted in program coordination within the Navy and between the Navy and other Federal and State agencies, and other interested parties. Specific efforts involved responding to interrogatories, coordinating workshops, meetings, and presentations; and preparing point papers, briefings, fact sheets, newsletters, etc. In addition to maintaining a very active and successful Web site ([www.navyseic.com](http://www.navyseic.com)) that includes the information, this effort addressed the following subtasks:

- Ozone-Depleting Substances, including alternative chlorofluorocarbon (CFC) refrigerants, alternative solvents/cleaning agents, and alternatives for Halon fire-protection systems.
- Shipboard Solid Waste, including R&D efforts, shipboard equipment, ship installations and operations, life-cycle management, Navy policy and regulations, National and international regulatory measures; and lessons learned relating to Navy shipboard solid waste management.
- Shipboard Liquid Waste, including oily waste, oily wastewater, compensated fuel systems, blackwater, graywater, and other liquid discharges.
- Pollution Prevention Afloat and Hazardous Materials, including R&D efforts, commercial product information, shipboard equipment, ship installations and operations, life-cycle management, Navy policy and regulations, and lessons learned relating to Navy shipboard pollution prevention.

### Ozone-Depleting Substances and Shipboard Environmental Information Clearinghouse Accomplishments

- “Shipboard Environmental Update” newsletter issues 2, 3 ,4, and 5: January 1998, June 1998, February 1999, and April 2000 (hardcopy and Web versions).
- U.S./Swedish handbook, “Environmental Considerations in the Systems Acquisition Process: A Handbook for Program Managers.”
- Stratospheric Ozone Protection Program seminar streaming video (Web version).
- “Guide to Environmental Compliance Afloat” (hardcopy and Web versions).
- “Your Ship, The Environment, and You” video.

- Navy ODS Advisories 95-01, 96-01C, 96-02 and 96-03.
- "Afloat Environmental Protection Coordinator Reference Library" CD.
- "ODS Conversion and Management Guide" (hardcopy and electronic versions).
- 2000 Fleetwide Environmental Questionnaire (FWEQ).
- Maintenance of SEIC Web site ([www.navyseic.com](http://www.navyseic.com)) and electronically provided environmental updates and relevant news to more than 300 Navy and DOD personnel.
- Fleetwide oily rag management plan.
- Responses to clearinghouse phone and e-mail inquiries about environmental issues from various Navy activities, DOD components and defense contractors.
- Technical assistance in support of the Office of Naval Research's Ocean, Atmosphere and Space Department (ONR 32).
- Revisions to Level 1 MILSPECs (i.e., those that directly reference ODSs) into the evolving DOD ODS SPECS and Standards database locally and on the World Wide Web (WWW).
- Hosting of the DOD Pollution Prevention Committee, ODS Subcommittee meetings.

## 5.2 ENVIRONMENTALLY SOUND SHIPS FOR THE 21<sup>ST</sup> CENTURY

Under this work area, GEO-CENTERS conducted a diverse array of activities relating to Navy ship environmental issues, problems, and challenges in support of the CNO's goal of achieving environmentally sound ships. GEO-CENTERS conducted studies, provided technical analyses, and prepared reports and publications in support of the Navy's Shipboard Pollution Abatement goals and environmental technology development program. Studies and related program support activities addressed the Navy environmental requirements for:

- Shipboard oily waste treatment systems
- Oil content monitors
- Non-oily wastewater treatment systems
- Solid waste management systems for processing shipboard plastics waste, garbage and trash, and medical wastes

- Hazardous waste treatment systems suitable for destroying or rendering non-hazardous all hazardous materials used on U.S. Navy ships

#### **Environmentally Sound Ships for the 21<sup>st</sup> Century Accomplishments**

- ESS-21 "Operating Responsibly with Nature" poster (Navy divers theme).
- "Arctic Environmental Atlas" (book, leather-bound book, and CD versions).
- Draft "Black Sea Integrated Coastal and Shelf Zone Monitoring and Modeling (INCOM) Program Science Plan" report.
- Annual "Proceedings of the Shipboard Waste Management RDT&E Program Reviews" (hardcopy, CD, and Web versions).
- "Afloat Medical Waste Management Guide."
- Paper titled, "Minimizing Environmental Impacts on Naval Forces: RDT&E Strategy for Environmental Systems Cross-Fleet Commonality" co-authored with SEA 05R24 for NSWC/ASNE "Engineering the Total Ship" Symposium.
- Paper titled, "US Navy Vision for Shipboard Thermal Destruction of Solid and Liquid Wastes," co-authored by SEA 03R24 for International Conference on Incineration and Thermal Treatment Technologies.
- Paper titled, "21<sup>st</sup> Century Vision for Shipboard Liquid Waste Management," co-authored by Anthony Nickens (SEA 03R1) and Joel Krinsky (SEA 03L).
- Design, fabrication, and testing of components of the DDG-51 model in the Compensated Ballast Program, including the diffusers, tank-level indicators, and fuel tanks.
- Support for the NATO Special Working Group 12 (SWG/12) on Maritime Environmental Protection (MEP) Meeting and the Partnership for Peace (PFP) effort.
- Support for the Clean Air Act to CNO (N457), including: reviewing emissions calculations for the conformity applicability analysis, hosting the Navy CAA Steering Committee, revising the Navy's Guidance on the General Conformity Rule, and editing the Navy facility database that is linked to the nonattainment database for the U.S.
- Support for NAVSEA's Ship Environmental Protection Process Action Team (SEP PAT), including distributing documents, such as the "Guide to Environmental Compliance Afloat," revising Fleetwide Environmental Questionnaire schedule, and preparing meeting minutes and summaries.

- Technical assistance in support of NAVSEA's enzymatic cleaner project, including developing test protocols, reports on the laboratory validation of protocols for evaluating the effectiveness of enzymatic cleaners and report on the development and validation of protocols, and test plans for shipboard evaluation of bilge and surface cleaners.
- Technical assistance in support of the Shipboard Medical Waste Research and Development program.
- Technical report on commercially available medical waste treatment systems.

## **APPENDIX 1**

### *List of Previous Reports Submitted under this Contract*

## Monthly Progress Reports

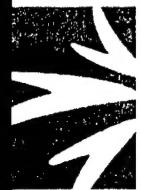
GC-PR-3062-01 dated October 15, 1996  
GC-PR-3062-02 dated November 15, 1996  
GC-PR-3062-03 dated December 15, 1996  
GC-PR-3062-04 dated January 15, 1997  
GC-PR-3062-05 dated February 15, 1997  
GC-PR-3062-06 dated March 15, 1997  
GC-PR-3062-07 dated April 15, 1997  
GC-PR-3062-08 dated May 15, 1997  
GC-PR-3062-09 dated June 15, 1997  
GC-PR-3062-10 dated July 15, 1997  
GC-PR-3062-11 dated August 15, 1997  
GC-PR-3062-12 dated September 15, 1997  
GC-PR-3062-13 dated October 15, 1997  
GC-PR-3062-14 dated November 14, 1997  
GC-PR-3062-15 dated December 15, 1997  
GC-PR-3062-16 dated January 15, 1998  
GC-PR-3062-16 dated February 15, 1998 (Numbered in error)  
GC-PR-3062-17 dated March 16, 1998  
GC-PR-3062-18 dated April 15, 1998  
GC-PR-3062-19 dated May 15, 1998  
GC-PR-3062-20 dated June 15, 1998  
GC-PR-3062-21 dated July 15, 1998  
GC-PR-3062-22 dated August 15, 1998  
GC-PR-3062-23 dated September 15, 1998  
GC-PR-3062-24 dated October 15, 1998  
GC-PR-3062-25 dated November 16, 1998  
GC-PR-3062-26 dated December 15, 1998  
GC-PR-3062-27 dated January 15, 1999  
GC-PR-3062-28 dated February 15, 1999  
GC-PR-3062-29 dated March 15, 1999  
GC-PR-3062-30 dated April 15, 1999  
GC-PR-3062-31 dated May 15, 1999  
GC-PR-3062-32 dated June 15, 1999  
GC-PR-3062-33 dated July 15, 1999  
GC-PR-3062-34 dated August 16, 1999  
GC-PR-3062-35 dated September 15, 1999  
GC-PR-3062-36 dated October 15, 1999  
GC-PR-3062-37 dated November 15, 1999  
GC-PR-3062-38 dated December 15, 1999

## Monthly Progress Reports (Continued)

GC-PR-3062-39 dated January 14, 2000  
GC-PR-3062-40 dated February 15, 2000  
GC-PR-3062-41 dated March 15, 2000  
GC-PR-3062-42 dated April 17, 2000  
GC-PR-3062-43 dated May 15, 2000  
GC-PR-3062-44 dated June 15, 2000  
GC-PR-3062-45 dated July 14, 2000  
GC-PR-3062-46 dated August 15, 2000  
GC-PR-3062-47 dated September 15, 2000  
GC-PR-3062-48 dated October 15, 2000

## APPENDIX 2

### *Glossary of Acronyms*



## Glossary of Acronyms

AIT	Alteration Installation Team
ASTM	American Society for Testing and Materials
ASW	Anti-Submarine Warfare
BGR	Bilgewater Generation Rate
CAA	Clean Air Act
CAD	Computer Assisted Drawing
CB	Chemical and Biological
CFC	Chlorofluorocarbon
CFD	Computational Fluid Dynamics
CNO	Chief of Naval Operations
COTR	Contract Officer's Technical Representative
COTS	Commercial off-the-shelf
CP	Cathodic Protection
DOD	Department of Defense
DOE	Department of Energy
DOF	Degree of Freedom
DTRA	Defense Threat Reduction Agency
EDM	Engineering Development Model
EF	Electric Field
EMI	Electromagnetic Interference
EPA	Environmental Protection Agency
ESS-21	Environmentally Sound Ships for the 21st Century
FEA	Finite Element Analysis
FEL	Frequency Engineering Laboratories
FEM	Finite Element Model
FWEQ	Fleet-Wide Environmental Questionnaire
FWR	Frequency Window Reduction
HEPA	High Efficiency Particulate Air (filter)
HM&E	Hull Mechanical and Electrical
ICCP	Impressed Current Cathodic Protection
ILS	Integrated Logistics System
IMS	Ion Mobility Spectroscopy
IPT	Integrated Product Team
MCM	Mine Countermeasures
MEP	Maritime Environmental Protection
MRC	Maintenance Requirement Card
MS&T	Materials Science and Technology
MTM	Mori-Tanaka Method
MTS	Materials Testing System
NACE	National Association of Corrosion Engineers
NAS	Naval Air Station
NATO	North Atlantic Treaty Organization

## Glossary of Acronyms (Continued)

NAVAIR	Naval Air Systems Command
NAVSEA	Naval Sea Systems Command
NAVSSES	Naval Ship Systems Engineering Station
NRL	Naval Research Laboratory
NRLMCF	NRL Marine Corrosion Facility
NSWC	Naval Surface Warfare Center
NSWCCD	Naval Surface Weapons Center, Carderock Division
NUWC	Naval Undersea Warfare Center
OAS	Ocean, Atmosphere, and Space Department (ONR)
OCM	Oil Content Monitor
ODS	Ozone Depleting Substance
ONR	Office of Naval Research
OVC	Outer Vacuum Case
OWP	Outer wing panel
OWS	Oil-Water Separator
P&ID	Process and Instrumentation Diagram
PAWDS	Plasma Arc Waste Destruction System
PFP	Partnership for Peace
PLC	Programmable Logic Controller
PLD	Pulsed Laser Deposition
PSM	Physical Scale Model
PWP	Plastic Waste Processor
SAW	Surface Acoustic Wave
SEIC	Shipboard Environmental Information Clearinghouse
SEM	Scanning Electron Microscope/Microscopy
SMA	Shape Memory Alloy
SPH	Smooth Particle Hydrodynamics
SSPC	Steel Structures Painting Council
STCC	Short Transverse Corrosion Crack
TDU	Trash Disposal Unit
UBS	Upgraded Baseline System
UCFEM	Unit Cell Finite Element Method
USN	United States Navy
UTI	Universal Technologies, Inc.
VOC	Volatile Organic Compound